OptiTools

Version 1

OptiTools is a collection of of utilities for calculations on optical fields used in OptiBPM, OptiFDTD, OptiMode, and OptiFiber. The following tools are available:

Overlap Integral Calculates power overlap integrals of fields. Can accept semi-vector and full vector data. In full-vector data, the input field has both major and minor components.

Gaussian Overlap Scanner Calculates power overlap integrals with Gaussian fields for a range of offsets. Applies to the BPM 2D or 3D fields

Overlap Integral Scanner Calculates the power overlap integrals for a range of field offsets.

Multiple Fields Creates a user generated field as a sum of given fields.

Multiple Gaussians Creates a user field as a sum of Gaussian fields.

Confinement Factor Calculates the portion of guided energy within an arbitrary rectangular boundary. Can accept semi-vector and full vector data.

Far Field Calculates the far-field radiation pattern from the near-field.

Mode 2D Finds the modal index and the modal field of any guided mode in a two-dimensional (planar) structure.

Code V Converter Converts ORA Code V files to Optiwave format files and vice versa.

EXFO OWA Converter For conversion of EXFO files

Zemax Converter Converts Zemax data files to and from Optiwave format files.

Matrix Converter Converts Optiwave field data files (f3d) to matrix format (txt)

Mesh Converter Transforms Optiwave field data files (f3d) by offsetting, scaling or resampling the data

Contents

1 Select and Launch a Tool

The OptiTools dialog box is opened from the Start menu. Select Opti Tools. This opens the OptiTools dialog box (see Figure 1).
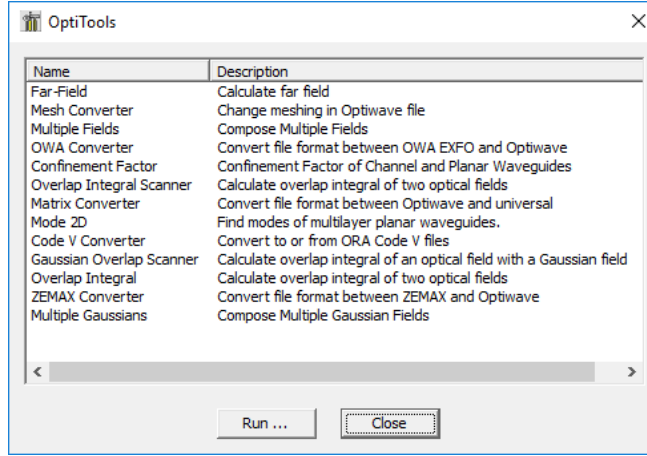
Figure 1: OptiTools dialog box

2 Overlap Integral

Overlap Integral calculates power overlap integrals of fields. It can accept both full-vector data and semi-vector data. In full-vector data, the input field has both major and minor components.

The Overlap Integral tool can use input fields with different sizes and mesh configurations. The relative position of the two fields can be modified by specifying an Offset in X and Y coordinates. The integration range is a user-specified rectangle within the intersection of the two fields, not over the whole domain.

Note: It is E2 that moves, not E1. The user specified rectangle Ω is on the same coordinate system as E1, see Figure 2

For example, in Figure 2, E1 is defined on the domain $x \in [1, 7]$ and $y \in [3, 7]$. The offset is [-4,4], and the domain of integration Ω can be specified within the intersection of E1 and E2. In this example, Ω is defined in the rectangle $x \in [4, 6]$ and $y \in [4, 6]$.

The power overlap integral in vector 3D is defined as:

$$P = \frac{|\iint_\Omega \mathbf{E}_1(x, y) \cdot \mathbf{E}_2^*(x, y) \, \mathrm{d}x\mathrm{d}y|^2}{\iint_{E_1} |\mathbf{E}_1(x, y)|^2 \, \mathrm{d}x\mathrm{d}y \, \iint_{E_2} |\mathbf{E}_2(x, y)|^2 \, \mathrm{d}x\mathrm{d}y} \tag{1}$$

By the E1 and E2 in the integration limits, we mean the domain of the respective functions. The squared magnitudes are interpreted as:

$$|\mathbf{E}|^2 = \mathbf{E} \cdot \mathbf{E}^* = E_x E_x^* + E_y E_y^* = |E_x|^2 + |E_y|^2 \tag{2}$$
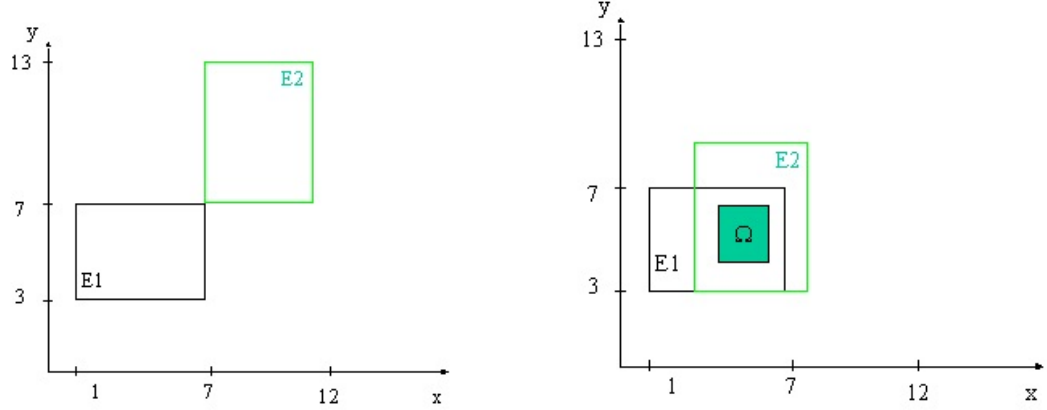
Figure 2: Two input fields, E1 and E2

The power is normalized so that any field, when overlapped with itself, will give a value of unity if the region of integration, Ω, is the extent of the whole function (i.e. in the case Ω is set to the domain of the function). Note that if a field is overlapped with itself, but integrated over an extent smaller than the domain, the result is the square of the confinement factor: power overlap integral of $\mathbf{E}(x, y)$ with itself $=$

$$
\frac{|\iint_\Omega \mathbf{E}(x,y) \cdot \mathbf{E}^*(x,y)\,\mathrm{d}x\mathrm{d}y|^2}{\iint_E |\mathbf{E}(x,y)|^2\,\mathrm{d}x\mathrm{d}y\ \iint_E |\mathbf{E}(x,y)|^2\,\mathrm{d}x\mathrm{d}y} = \left|\frac{\iint_\Omega |\mathbf{E}(x,y)|^2\,\mathrm{d}x\mathrm{d}y}{\iint_E |\mathbf{E}(x,y)|^2\,\mathrm{d}x\mathrm{d}y}\right|^2
\tag{3}
$$

The confinement factor is defined as

$$
\Gamma = \frac{\iint_\Omega |\mathbf{E}(x,y)|^2\,\mathrm{d}x\mathrm{d}y}{\iint_E |\mathbf{E}(x,y)|^2\,\mathrm{d}x\mathrm{d}y}
\tag{4}
$$

and so from equation (3), the power overlap integral of a field with itself over the region is the square of the confinement factor of that field to the region. The Power Overlap Integral and Confinement factor are defined for scalar, semi vector, and 2D in a similar way.

2.1   2D Overlap Integral

The 2D Overlap Integral dialog box allows you to calculate overlap integrals in 2D fields (see Figure 3).

Note: If you access the Overlap Integral tool via the 2D Mode Solver, the data file for Input Field 1 is already loaded.

Input Data Specify the two 2D fields and the overlap regions

    Input Field 1 name of a .f2d file containing the first input field.

Figure 3: The 2D Overlap Integral dialog box

Input Field 2 name of a .f2d file containing the second input field.

Get Data Once the two .f2d files have been selected, click Get Data to have the utility read the field data. Once the data are read, the following fields will be available (See Figure 3)

Offset X This number indicates the distance the second field is moved before the overlap integral calculation is done

Subdivisions this is the number of subdivisions of mesh intervals in the overlap integral. The subdivisions option is related to the space discretization where the overlap integral will be solved. The meshes of the two fields can be different, and the offset is arbitrary. We want to obtain an integral with an accuracy that is consistent with the mesh representation of the functions in the integrand. This requires oversampling the integrand, which is achieved by subdividing the smaller mesh interval into the specified number of points. The accuracy improves with more subdivisions, but the execution time slows down. More accurate results can be obtained by using a number as large as 10 for subdivisions, but the accuracy is not likely to improve by further increasing the subdivisions beyond 10.

Region of Integration X lower and X upper define, using the co-ordinate system of Input Field 1, the range of integration for the overlap integral (it is an integration over a single variable in the 2D Overlap Integral case).

Note: The following fields are never available in the 2D Overlap Integral dialog box:

OffsetY

RegionY Y Upper and Y Lower

Statistics The resulting overlap integral displays in percent and in decibels.

Status Two small read-only windows display the current operation status (for example, Idle, Loading, or Calculating) and the completed percentage of the operation (progress bar).

2.2   3D Overlap Integral

The 3D Overlap Integral dialog box allows you to calculate overlap integrals of 3D fields (see Figure 4)
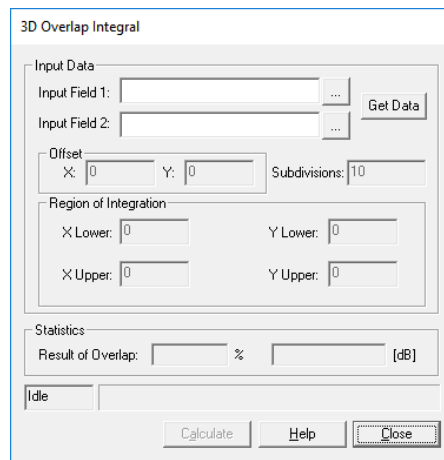
Figure 4: The 3D Overlap Integral dialog box

Input Data Specify the two f3d fields and the overlap regions

    Input Field 1 name of a .f3d file containing the first input field.
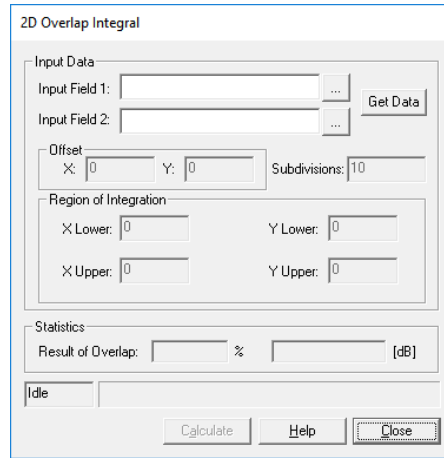
    Input Field 2 name of a .f3d file containing the second input field.

Get Data Once the two .f3d files have been selected, click Get Data to have the utility read the field data. Once the data are read, the following fields will be available (See Figure 4)

Offset X and Y Specifies the translation of field E2 before the overlap integral is done.

Subdivisions this is the number of subdivisions of mesh intervals in the overlap integral. The subdivisions option is related to the space discretization where the overlap integral will be solved. The meshes of the two fields can be different, and the offset is arbitrary. We want to obtain an integral with an accuracy that is consistent with the mesh representation of the functions in the integrand. This requires oversampling the integrand,

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which is achieved by subdividing the smaller mesh interval into the specified number of points. The accuracy improves with more subdivisions, but the execution time slows down. More accurate results can be obtained by using a number as large as 10 for subdivisions, but the accuracy is not likely to improve by further increasing the subdivisions beyond 10.

Region of Integration X lower and X upper define, using the co-ordinate system of Input Field 1, the range of integration for the overlap integral. See Figure 2.

Statistics The resulting overlap integral displays in percent and in decibels.

Status Two small read-only windows display the current operation status (for example, Idle, Loading, or Calculating) and the completed percentage of the operation (progress bar).

3 Gaussian Overlap Scanner

The Gaussian Overlap Scanner applies to files with 2D or 3D optical field data. The program calculates the power overlap integral (POI) (see Equation 1) of a given complex field and a Gaussian field, where the Gaussian center position (x_c, y_c) is varying or scanned within the mesh limits.

The Gaussian field is a Gaussian distribution defined from a center point x_c, y_c and halfwidths σ_x and σ_y.

$$G(x, y) = \exp\left[-\left(\frac{x - x_c}{\sigma_x} \right)^2 - \left(\frac{y - y_c}{\sigma_y} \right)^2 \right] \tag{5}$$

In 2D, the Gauss function reduces to the case $y = y_c$. The Gaussian field center is at coordinates (x_c, y_c) where G has value of unity. At any point on a ellipse with semi axes σ_x and σ_y, the value is $1/e$.

Input Field name and location of the .f3d file with the optical field data

Number of Points in Mesh displays the number of discretization points in the optical field

Mesh Widths displays the field window size in microns

Gaussian Field Half Widths X and Y width of the current Gaussian field σ_x and σ_y

X Limits of Gaussian Center Position displays limits for X coordinates of the Gaussian field center, x_c.

Y Limits of Gaussian Center Position displays limits for Y coordinates of the Gaussian field center, y_c.
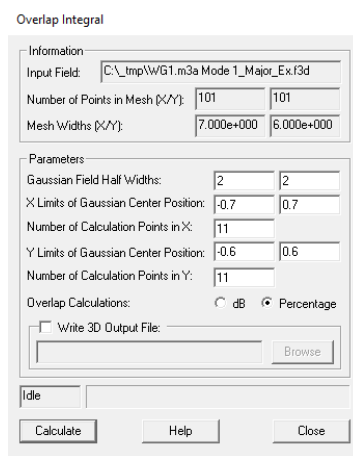
Figure 5: Gaussian Overlap Integral Scanner dialog box

Number of Calculation Points in X specifies the number of calculation points for X

Number of Calculation Points in Y specifies the number of calculation points for Y

Overlap Calculations select the format of the overlap calculations, output can be expressed in dB or Percentage

Write 3D Output file enable to provide a file name and path. For 2D calculations, use a .f2d file extension, so that Optiwave 2D viewers can be used to view the scanned results.

Calculate click to start the calculations. At the end of the calculation, a dialog box appears stating the maximum overlap integral and the displacement at which it was obtained. The results of all overlap integrals are sent to the file in the Overlap Calculations field.

4 Overlap Integral Scanner

The Overlap Integral Scanner calculates the overlap integral of two given fields scanning the position of the second field. This feature works in a similar manner to the Gaussian Overlap Scanner. The number of calculation points is fixed, but you can change the limits of the second field position. The Overlap Integral Scanner involves the repeated application of the Overlap Integral for various displacements of the second field (E2 of Figure 2). To open the Overlap Integral Scanner, in the OptiBPM Utilities dialog box, click Overlap Integral Scanner to get the dialog box (see Figure 6). Select either the 2D or 3D Overlap Integral, as appropriate.
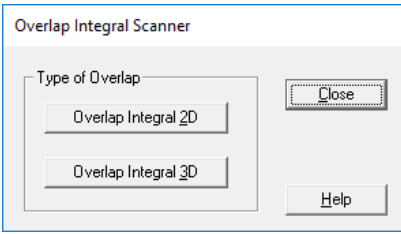
Figure 6: Overlap Integral Scanner dialog box

Overlap Integral 2D Integral of two one-dimensional fields in Optiwave format *.f2d

Overlap Integral 3D Integral of two two-dimensional fields in Optiwave format *.f3d

After selecting either of these, the Input Fields dialog box opens. Browse to select the path and name of the two Optiwave format files with the optical field data.

4.1   2D Overlap Integral Scanner
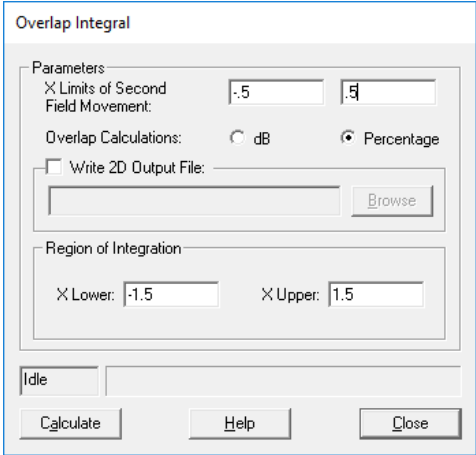
Figure 7: 2D Overlap Integral Scanner dialog box

X Limits of Second Field Movement controls the range of X displacement of second field.

Overlap Calculations select the format of the overlap calculations, dB or Percentage.

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Write 2D file enable to provide a file name and path. Use a .f2d file extension, so that Optiwave 2D viewers can view the scanned results.

Region of Integration Specifies region of integration, Ω where the overlap integration is performed

Status fields Two small read-only windows display the current operation status (Idle, Loading, or Calculating) and the completed percentage of the operation (progress bar).

4.2   3D Overlap Integral Scanner
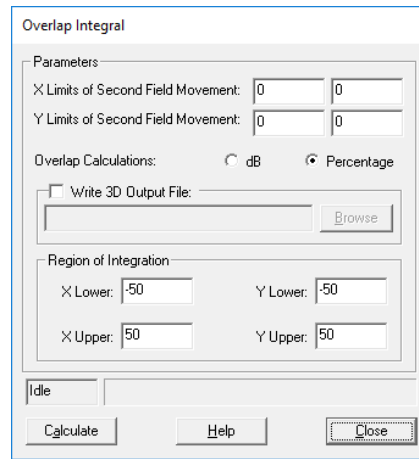
Figure 8: 3D Overlap Integral Scanner dialog box

X Limits of Second Field Movement controls the range of X displacement of second field.

Y Limits of Second Field Movement controls the range of Y displacement of second field. The number of points in the scan is taken from the mesh size of the first or second field (the smaller of the two mesh sizes is used).

Overlap Calculations select the format of the overlap calculations, dB or Percentage.

Write 3D file enable to provide a file name and path. Use a .f3d file extension, so that Optiwave 3D viewers can view the scanned results.

Region of Integration Specifies region of integration, Ω, as in equation (1), where the overlap integration is performed. The numbers in the fields are coordinates in the system of field E1.

  X Lower bottom left corner of the rectangle Ω

Status fields Two small read-only windows display the current operation status (Idle, Loading, or Calculating) and the completed percentage of the operation (progress bar).

**Calculate** click to start the calculations. At the end of the calculation, a dialog box appears stating the maximum overlap integral and the displacement at which it was obtained. The results of all overlap integrals are sent to the file in the Output File field.

5   Multiple Fields

The Multiple Fields utility calculates a user field E as a weighted sum of given fields E1, E2.....EN with specified weights and phase changes. To open the Multiple Fields, in the OptiTools dialog box, select Multiple Fields.
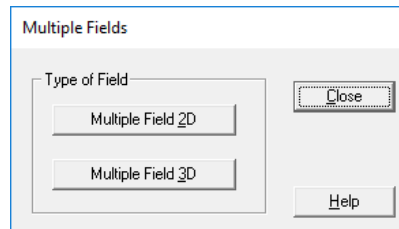
Figure 9: Multiple Fields dialog box

Multiple Field 2D addition of fields with one independent variable (*.f2d)

Multiple Field 3D addition of fields with two independent variables (*.f3d)

Field to add browse to an existing file with optical field data

Weight Factor enter the coefficient that multiplies the amplitude or intensity of the Field to add

Phase Change enter the phase factor that changes the phase of the Field to add in degrees

Fields already added lists all fields added so far

Add Field click to add the Field to add to the list

Finish click to calculate the sum of all fields in the list

At the end of the calculations, there will be a box asking if the result is to be normalized. If selected, the result will be normalized so that the maximum amplitude is 1.
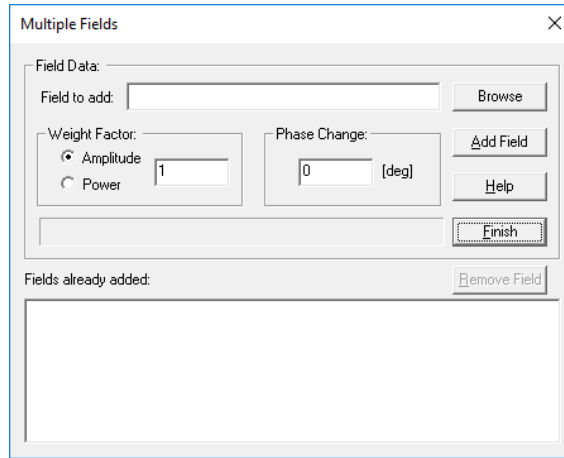
Figure 10: Multiple Fields dialog box

6   Multiple Gaussians

Multiple Gaussians will create a sum of Gaussian fields G1, G2, G3... each with different centers and halfwidths, as defined in equation (5). The Gaussian fields can be added with different amplitudes and phases.
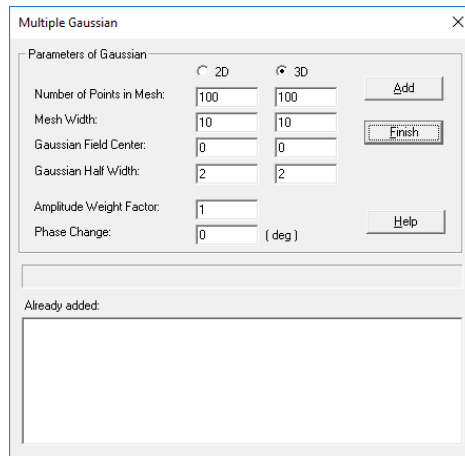
Figure 11: Multiple Gaussians dialog box

Number of Points in Mesh enter the number of discretization points of the Gaussian field. After the first entry, followed by Add, the Number of Points in Mesh cannot be changed for subsequent fields.

Mesh Width enter the mesh width in microns. This specifies the XY domain.

After the first entry, followed by Add, the Mesh Width cannot be changed
for subsequent fields.

Gaussian Field Center enter X and Y coordinates of the Gaussian center
(x_c, y_c)

Gaussian Half Width enter X and Y widths of the current Gaussian field
σ_x, σ_y .

Amplitude Weight Factor this amplitude will be applied to the current Gaussian field

Phase Change this phase will be applied to the current Gaussian field before
adding it to the list.

Add click to add the current field to the list

Finish click to calculate the sum of all fields in the list.

At the end of the calculation, there will be a box asking if the result is to be
normalized. If selected, the result will be normalized so that the maximum
amplitude is 1.

7   Confinement Factor
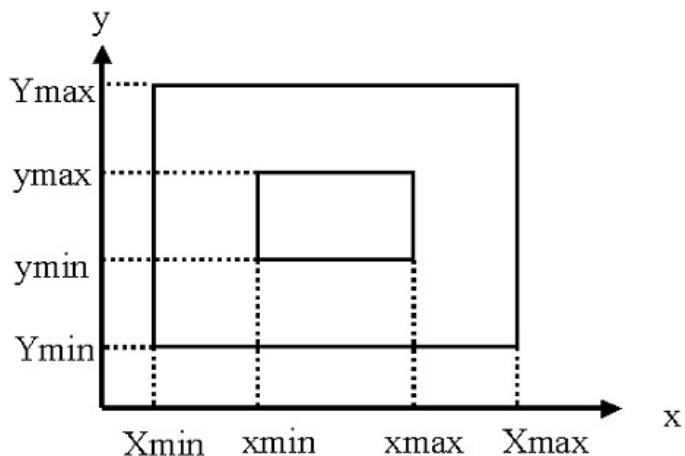
Figure 12: Confinement Factor

The confinement factor, Γ, is defined by the optical field over the rectangle
bounded on the lower left corner by (Xmin, Ymin) and on the upper right by
(Xmax, Ymax). The confinement factor is the fraction of power to be found in
the smaller rectangular region bounded by (xmin, ymin), (xmax, ymax).

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$$\Gamma = \frac{\int_{ymin}^{ymax} \int_{xmin}^{xmax} |\mathbf{E}(x,y)|^2 \, \mathrm{d}x \mathrm{d}y}{\int_{Ymin}^{Ymax} \int_{Xmin}^{Xmax} |\mathbf{E}(x,y)|^2 \, \mathrm{d}x \mathrm{d}y} \tag{6}$$

The squared magnitude is interpreted as

$$|\mathbf{E}|^2 = \mathbf{E} \cdot \mathbf{E}^* = E_x E_x^* + E_y E_y^* = |E_x|^2 + |E_y|^2 \tag{7}$$

In the case of scalar fields and 2D fields, similar definitions are used.

Confinement Factor calculates a portion of guided energy within waveguide boundaries. To open the Confinement Factor dialog box, in the OptiTools dialog box, select Confinement Factor (see Figure 1).
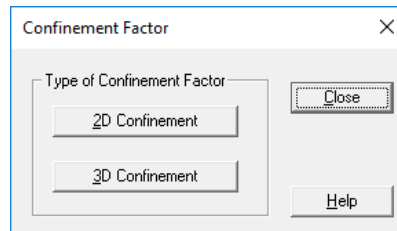
2D Confinement calculate confinement factor for optical fields with one independent variable (*.f2d)

3D Confinement calculate confinement factor for optical fields with two independent variables (*.f3d)

Click 2D Confinement or 3D Confinement to open the Open dialog box. Select a file, and click Open to open the Confinement Factor - 2D dialog box, or the Confinement Factor - 3D dialog box.

Field displays the path and file name of the file with the optical field data

Xmin, Ymin, Xmax, Ymax as in Figure 12

xmin, ymin, xmax, ymax as in Figure 12

XNo displays the number of X axis mesh points in the data file

YNo displays the number of Y axis mesh points in the data file

Use Mesh Points select this if the region Ω is to be specified as mesh points on the data file, instead of by coordinates xmin, ymin, xmax, ymax.

Confinement Factor displays the calculated confinement factor in percent

Compute starts the confinement factor calculation
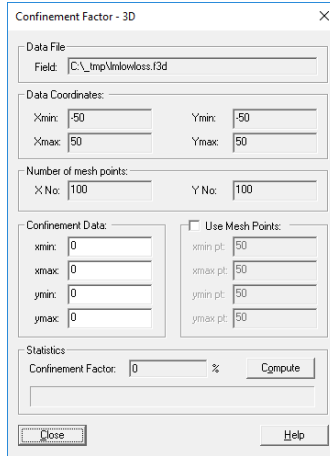
Figure 13: The 3D Confinement Factor dialog box

8 Far Field

The Far Field tool calculates the far field pattern from an optical field in the near field. The output is an intensity as a function of angles (in degrees) from the optical axis. The far field distribution can be observed and measured, thereby providing an important tool for estimating the characteristics of a given waveguide. The far field distribution can be derived from the Fraunhofer diffraction pattern of its near field. To calculate the far-field intensity pattern, the Fast Fourier transform is used first to calculate the Fraunhofer integral[1]. Next, the result is re-sampled in order to have uniform angular sampling. The intensity of radiation (the modulus squared of the result) is is normalized such that the maximum value is 1.0. The normalized intensity is displayed with the angles as coordinates.

8.1 Far Field 2D, Far Field 3D

The narrow angle far-field transform being used in OptiTools is based on the Fraunhofer approximation:

$$E(x, y, z = d) \approx \frac{je^{jkd}e^{j\frac{k}{2d}(x^2+y^2)}}{\lambda d} \iint E(x', y', 0)e^{-j\frac{k}{d}(xx'+yy')}dx'dy' \qquad (8)$$

At a large distance d, the far field position can be expressed by the far field angle approximation:

$$\tan(\theta_x) = \frac{x}{d}, \ \tan(\theta_y) = \frac{y}{d} \qquad (9)$$

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[1] Justin Peatros and Harold Stokes, Physics of Light and Optics
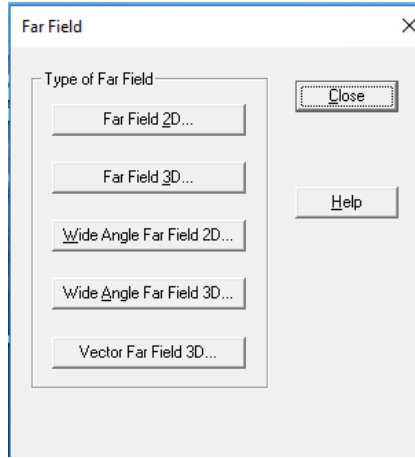
Figure 14: The Far Field selection dialog box

where the x-directional angle, θ_x, is the angle between the original yz-plane and the shortest straight line connecting the point and the Y axis, and y-directional angle, θ_y, is the angle between the orginal xz-plane and the shortest straight line connecting the point and the X axis. The far field angles are shown below in Figure 15.
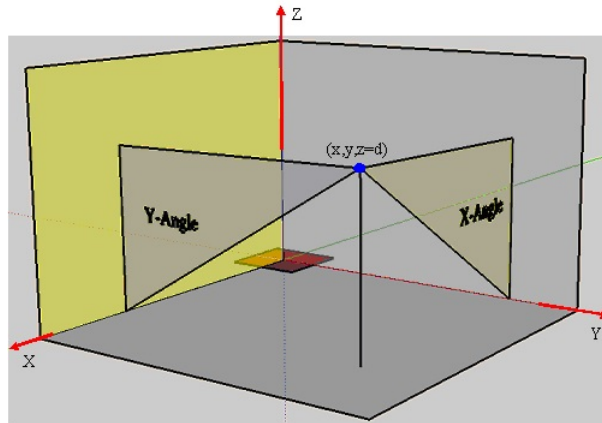
Figure 15: Coordinate system of Far Fields. The red region near the origin is the near field

With the choice of angles in (9), the Fraunhofer formula (8) will become

$$E(\theta_x, \theta_y) \propto \iint E(x', y', 0)e^{-jn\frac{2\pi}{\lambda}\left[x'\tan(\theta_x)+y'\tan(\theta_y)\right]}dx'dy' \qquad (10)$$

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Note that the above formula assumes the far field is far from the near field. OptiTools uses Equation (10) to calculate the narrow angle far field transform.
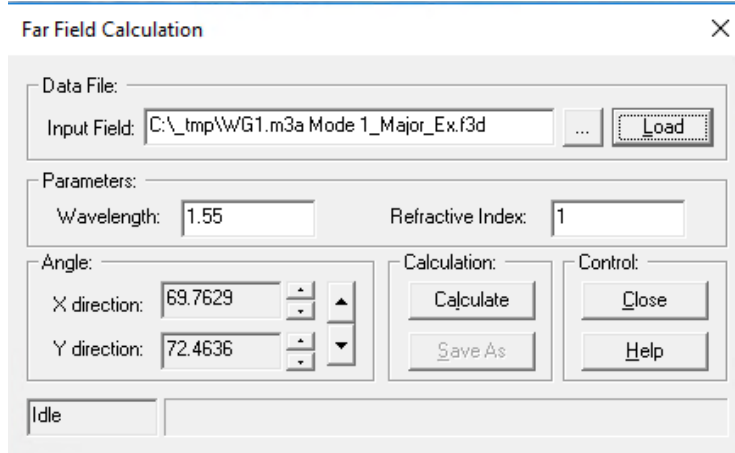
Input Field enter the path and name of the file with the near field

Load click to load the selected input field

Wavelength enter the optical wavelength in microns

Refractive Index enter the refractive index of the medium

X direction angle in the XZ plane

Y direction angle in the YZ plane

8.2   Wide Angle Far Field

Wide angle far field transform is based on the Fresnel-Kirchhoff diffraction formula:

$$E(x, y, z = d) = -\frac{j}{\lambda} \iint E(x', y', 0) \frac{e^{jkR}}{R} \left[\frac{1 + \cos(\mathbf{R}, \mathbf{z})}{2} \right] dx' dy' \qquad (11)$$

where R is the vector from near-field to far-field.

The far-field position can be expressed with the far field angle and the far field distance z=d. Therefore, in the wide angle far field transform, user needs to specify the far field distance. In the wide angle Far Field dialog boxes, a space is provided to enter the distance.

8.3 Vector Far Field

For cases where the field cannot be approximated by a scalar field, the far field transform can be calculated using the surface equivalence theorem. This theory is taken from Chapter 8.4 of Taflove and Hagness[2], for a complete explanation, please see this source.

The basis for this transformation is that knowledge of the electric and magnetic surface currents on any closed surface can be used to calculate the electromagnetic fields at any other point via an integration on the surface. In an FDTD algorithm, it is natural to choose a rectangular prism made from planes that match the Yee mesh, and that the surface should be one of the bounding surfaces of the prism. Those surfaces are planes normal to $\hat{\mathbf{x}}$, $\hat{\mathbf{y}}$, or $\hat{\mathbf{z}}$. The surface currents are given by cross products of the fields with the normal vector to the surface:

$$\mathbf{J_s} = \hat{\mathbf{n}} \times \mathbf{H_1} \tag{12}$$

$$\mathbf{M_s} = -\hat{\mathbf{n}} \times \mathbf{E_1} \tag{13}$$

where $\mathbf{J_s}$ is the electric surface current and $\mathbf{M_s}$ is the magnetic current on the surface. Suppose the electric and magnetic fields are to be calculated at position $\mathbf{r}$ and the source position (on the surface) is given by $\mathbf{r'}$. The vector pointing from source to observation point will be

$$\mathbf{R} = \mathbf{r} - \mathbf{r'} \tag{14}$$

For large distances the following approximation can be made:

$$R = \sqrt{r^2 - r'^2 - 2rr'cos\psi} \approx r - r'cos\psi \tag{15}$$

where ψ is the angle between $\mathbf{r}$ and $\mathbf{r'}$, R is the length of $\mathbf{R}$, r is the length of $\mathbf{r}$, and r' is the length of $\mathbf{r'}$.

The electric and magnetic fields are then given by:

$$E_r = 0 \tag{16}$$

$$E_\theta = -\frac{jke^{-jkr}}{4\pi r}(L_\phi + \eta_0 N_\theta) \tag{17}$$

$$E_\phi = +\frac{jke^{-jkr}}{4\pi r}(L_\theta - \eta_0 N_\phi) \tag{18}$$

$$H_r = 0 \tag{19}$$

$$H_\theta = +\frac{jke^{-jkr}}{4\pi r}(N_\phi - L_\theta/\eta_0) \tag{20}$$

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[2]A. Taflove and S. C. Hagness, Computational Electrodynamics: The Finite-Difference Time-Domain Method, Third Edition.ch. 8, sec. 4, pp. 338-343 (2005)

$$H_\phi = -\frac{jke^{-jkr}}{4\pi r}(N_\theta + L_\phi/\eta_0) \qquad (21)$$

where $\eta_0 = \sqrt{\mu_0/\epsilon_0}$ is the intrinsic impedance of free space, k is the wavenumber and r is the magnitude of the observation position vector. Finally, intermediate expressions L_θ, L_ϕ, N_θ, and N_ϕ are given by:

$$N_\theta = \iint_S (J_x cos\theta cos\phi + J_y cos\theta sin\phi - J_z sin\theta)e^{+jkr'cos\psi}dS \qquad (22)$$

$$N_\phi = \iint_S (-J_x sin\phi + J_y cos\phi)e^{+jkr'cos\psi}dS \qquad (23)$$

$$L_\theta = \iint_S (M_x cos\theta cos\phi + M_y cos\theta sin\phi - M_z sin\theta)e^{+jkr'cos\psi}dS \qquad (24)$$

$$L_\phi = \iint_S (-M_x sin\phi + M_y cos\phi)e^{+jkr'cos\psi}dS \qquad (25)$$

The surface, S, in the integrals (22) to (25) is the optical near field. In Figure 15, the optical near field is the red square shown on the plane $Z = 0$. In this example, the normal vector $\hat{\mathbf{n}}$ is $\hat{\mathbf{z}}$, and the surface is in the X-Y plane.
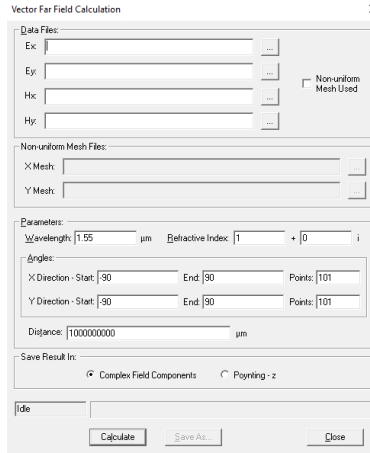
Figure 16: Vector Far Field dialog box

Data Files browse to or enter the path and name of files containing tangential components of electric and magnetic fields in the near field. The labels presume the near field is in the X-Y plane, but either of the two other planes could be used.

Nonuniform Mesh If the near fields are defined on nonuniform meshes, enable the check box and enter the path and name of files containing the nonuniform mesh data for the X and Y axes.

Wavelength free space wavelength of the light

Refractive Index refractive index of the medium of long distance propagation.

Angles specify angles for far field calculation

Distance distance from near field to observation plane

9   Mode 2D

The Mode Solver 2D finds the modal index and the modal field of guided modes in a two-dimensional (planar) structure. Two methods for mode solving are available:

Modes of Planar Waveguides (MPW)   Use this option if you want to solve for optical modes on a planar waveguide using the transfer matrix method. This is the usual method for finding real guided modes on planar waveguides.

Correlation Function Method (CFM)   Use this option if you want to solve for optical modes on a planar waveguide using the Correlation Function Method. This method finds modes by simulating optical propagation by the Beam Propagation Method, and then deduces the modes by correlation.

For the MPW simulations, modal solutions can be automatically scanned using the Scan Parameters option. Thickness, refractive index of layers, and other parameters can be scanned individually or in combinations defined using a programmable spreadsheet. Using the solvers, you may find modal indices that are needed to convert a 3D problem to a 2D problem by the Effective Index Method.

To start the 2D Mode Solver, select it from the OptiTools dialog box (Figure 1), and click Run... to get the 2D Mode Solver dialog box
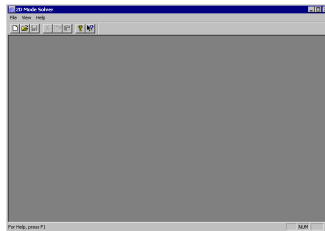
Figure 17: 2D Mode Solver

To enter a planar dielectric waveguide, start a new project by selecting New from the File menu. Select one of the three project options. The first one will solve by the traditional transfer matrix method. The second two both use the Correlation Function Method (CFM).

- Modes of Planar Waveguides(MPW)

- Correlation Function Method (CFM)

- User Defined File (CFM)

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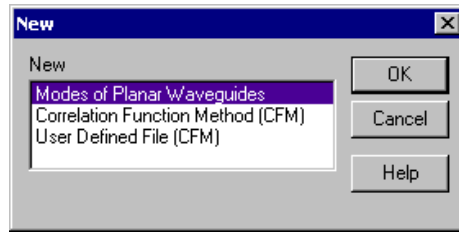
Figure 18: The New dialog box

9.1   Modes of Planar Waveguides (MPW)

Use this option to solve for optical modes on a planar waveguide using the transfer matrix method. Enter the 2D structure by adding layers. The refractive index must be a real number. Also enter the refractive index and thickness of the cladding and substrate (top layer and bottom layer).
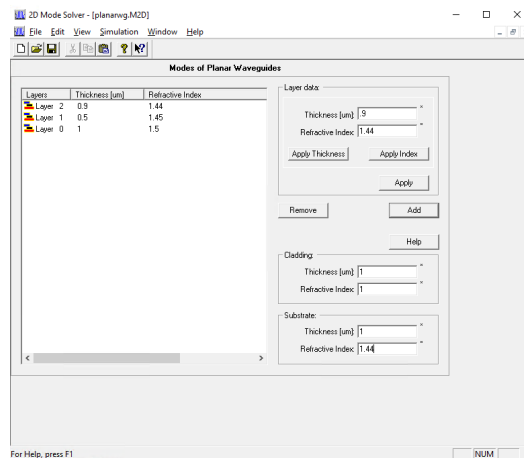
Figure 19: Dialog box to enter layer structure

Use the data fields and control buttons to enter a sequence of refractive indices and layer widths. There are also data fields to enter data for the cladding and substrate layers. They are oriented as shown in Figure 20

In the MPW option, the Global Parameters are accessed from Simulation >>Global Parameters... and they are as follows:

Wavelength enter the vacuum optical wavelength

Wafer Thickness This is used for the display. The wafer thickness is the sum of substrate, layers and cladding thicknesses.

Polarization Choose TE to find the transverse electric modes, TM to find the transverse magnetic modes

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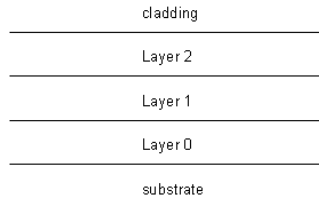
Figure 20: Orientation of layers in the planar waveguide
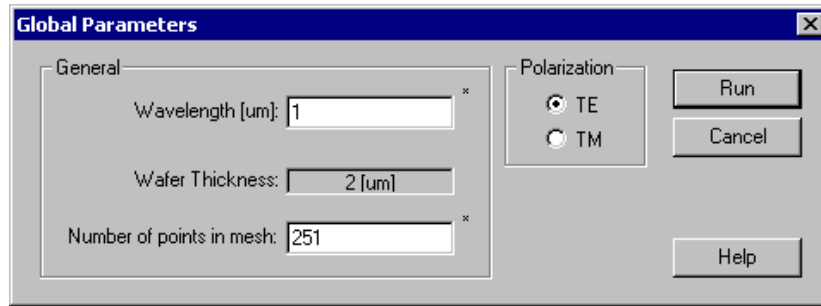
Figure 21: Global Parameters of MPW mode 2D solver

Number of points in mesh this is for the display. Enter the desired resolution.

9.2 Scan Parameters

Available in the MPW solver, this option enables the automatic repeating of simulations in a loop-like manner. Since a number of parameters can be changed simultaneously in each loop iteration, these parameters are called scan parameters. Access this feature from from Simulation >>Scan Parameters...

Any of the symbolic parameters from the list of symbolic parameters can be scanned. The list may contain parameters that are not directly related to waveguides and the design parameters (for example, the wavelength, waveguide refractive index, and start and end waveguide width). Among the design parameters, there is a group of parameters that can be used for scanning. The scannable parameters are marked by a star symbol on the data entry dialog boxes. For example, in the Global Data dialog box, the Wavelength data entry is marked by the star symbol. Assume that you do not have a parameter Lambda on your list of variables. If you type Lambda as the Global Data entry, instead of providing a number, the program prompts you to accept Lambda as a new parameter that can vary and adds its name and value to the list of symbolic parameters. All existing scannable parameters are listed as unassigned parameters in the Scan Parameters dialog box.
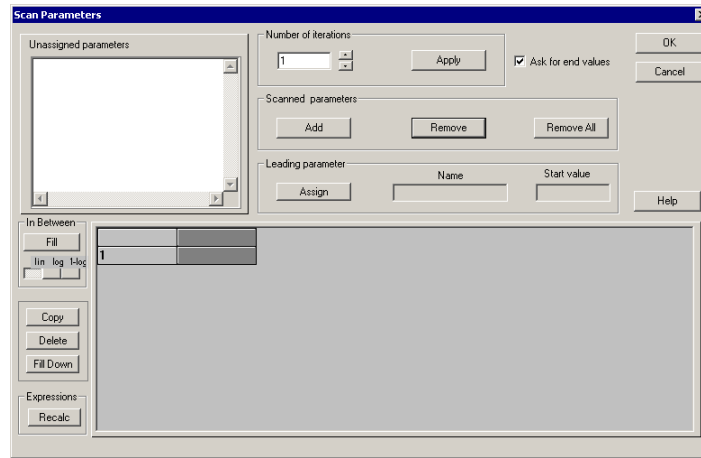
Figure 22: Scan Parameters dialog box

The Scan Parameters dialog box consists of two main sections: in the upper section, you configure the iterations; in the lower section, you work with a spreadsheet for establishing what values of the parameters are used in each iteration.

Unassigned Parameters Lists the parameters that can be used for the scan calculations

Number of iterations Displays the number of iterations in the loop. The iteration number defines the number of spreadsheet rows.

Ask for end values when enabled, prompts for end values of scanned parameters in the spreadsheet.

Scanned parameters Add a parameter from the Unassigned Parameters list or remove parameter column from the spreadsheet. Adding a parameter creates a corresponding column in the spreadsheet.

Leading parameter assign a leading parameter among the scanned parameters that will be displayed in the Report dialog box during the simulations.

In Between Fills in blank rows between selected start and end rows by using a linear, logarithm, or (1-log) function. The start and end rows must not be blank.

Copy Copies a first value from spreadsheet selection to the entire selection.

Delete Deletes the selected parameters

Fill Down Fills down the column linearly using the linear step taken from first two values.

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Expressions Recalc recalculates mathematical expressions used in the spreadsheet. For example, you can simultaneously change the wavelength, width, or refractive index of a waveguide. The resulting data will be identified by the corresponding iteration number. You designate a parameter as the leading parameter. The resulting data will be identified by the iterated values of that leading parameter. The Recalc option is useful for the displaying of results.

9.3   Output Data Files

Also available in the MPW solver, the simulation output data can be saved in selected files as sepecified by the Output Data Files dialog box. If Mode 2D is used in the loop-like simulations from the Scan Parameters option, the resulting output files are additionally numbered according to the loop iteration numbers.

To open the Output Data Files dialog box, from the Simulation menu, select Output Data Files

9.4   Correlation Function Method (CFM)

Use this option for solving optical modes on a planar waveguide using the Correlation Function Method. To start the CFM, select it from the New dialog box in Figure 18. Enter the layer data for the planar waveguide as shown in Figure 19.

In the CFM option, the Global Parameters are accessed from Simulation >>Global Parameters...

Figure 23: Global Parameters of CFM mode 2D solver

The CFM solver finds modes by analysing multi mode propagation. The propagation is calculated with the Beam Propagation Method. Since there is propagation, the CFM method needs a starting field. Depending on the starting
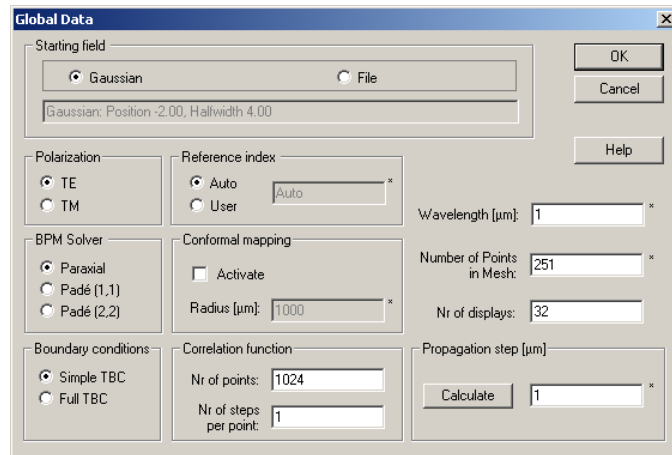
field, different modes can be excited. For a complete solution, the solver runs the propagation twice first time to find modal propagation constants, and the second time to calculate modal fields. It is necessary to set up parameters for the BPM propagation and for the correlation function calculations.

Starting Field The starting field is the field distribution at the start of propagation. There are two choices of the starting field amplitude:

Gaussian initialize a Gaussian starting field. Select the distribution parameters.

File Initializes a field from a user file in the *.f2d format

Polarization Two field polarization options are possible:

BPM Solver There are three solver options:

Paraxial Paraxial BPM solver

Padé (1,1) Wide-angle solver based on the Padé (1,1) approximant

Padé (2,2) Wide-angle solver based on the Padé (2,2) approximant

The simplest and fastest solver is based on the paraxial method. The results are accurate for propagation cone angles not exceeding 15-20 degrees. The wide-angle solvers are more precise than the paraxial solver for larger angles but are also more time-consuming. Solvers based on higher Pad approximants also allow for simulations of structures with a larger refractive index contrast.

Boundary conditions An important problem in waveguide modeling is the treatment of radiation waves since the radiation tends to reflect from the problem boundaries back into the solution region where it causes unwanted interference. A common way to prevent boundary reflection is through the insertion of artificial absorption regions that are close to the boundaries. Unfortunately, this method cannot be implemented in BPM2D because its application is problem-dependent. The absorption method requires an adjustment of the absorption parameters which is not appropriate for a general purpose software. Consequently, the most natural way to escape unwanted reflections from the boundaries is to introduce transparent boundary conditions (TBC) that are not problem-dependent. BPM2D uses the transparent boundary condition called TBC, which allows the optical field to flow out through the boundaries.

Reference index The reference index is a constant refractive index used in the slowly varying envelope approximation in the BPM2D calculations.

Conformal mapping employs the conformal mapping method for finding modes of bent waveguides. The bend is taken to be in the upward direction.

Correlation function The correlation between the starting field and the propagating field is the basis for determining waveguide modes. Peaks of the correlation function correspond to excited modes. Nr of points: Must be a power of 2; adjusts the precision of modal indices; more points means better precision. Nr of steps per point: Number of propagation steps per correlation function point; adjusts index limits where the solver search looks for modes; more steps expands the searching limits.

Wavelength Define the wavelength value used in propagation simulations. The wavelength is assumed to be the vacuum wavelength.

Number of Points in Mesh The simulation results can be very sensitive to the number of mesh points. In general, the use of more mesh points results in better precision. In the simulation of multimode waveguides, it is suggested that you use at least several points per eigenmode. For example, for a ten-mode waveguide, the number of points within the waveguide boundaries should be twenty or more. The minimum number of mesh points is 19. The maximum number of mesh points is not limited in BPM2D and depends solely on the computer memory available. However, too large a number of mesh points may lead to long computations and round-off errors.

Nr of Displays This is the number of layout cross-sections that are displayed and saved to output data files. The Number of Displays parameter is usually much less than the number of propagation steps. While the propagation step is a numerical parameter, the number of displays is not and does not affect the simulation accuracy. The number of displays is limited by how many display points your computer can handle in the memory. Usually, 50 displays is sufficient for simple devices.

Propagation Step The options in the Propagation Step section allow you to define the number of propagation steps and to do calculations. The program suggests the step size that results in good precision. However, the numerical method used in BPM2D is unconditionally stable, and you can enter a step size larger than the suggested one. The suggested value is usually smaller than the precision-safe value.

9.5 User Defined File (CFM)

Use this option for solving optical modes on a planar waveguide when the planar waveguide is specified as a refractive index distribution that is provided from a file. This option will use the CF method. To start the User Defined option, select it from the New dialog box in Figure 18.
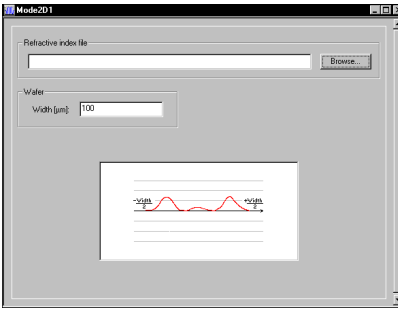
Figure 24: Specify User Defined Refractive Index file

10   Code V Converter

Optiwave supplies software for waveguide optics. Waveguides are of size (in the transverse plane) comparable to an optical wavelength. Although it is theoretically possible to analyze free space or bulk optical components such as lenses and mirrors by the solution of Maxwell's equations, generally it is more practical to make use of approximations commonly used in ray optics. Optiwave does not supply ray optics software, but OptiTools has a utility to convert the data of another software, Code V of Optical Research Associates. In Code V, you can analyze bulk optics such as mirrors and lenses using ray tracing techniques. If at some part of the system, the rays converge to a focus and the light enters an optical waveguide, Code V can be used together with Optiwave to analyze the whole system. Code V can use ray tracing to determine the optical field distribution at the focal point, and the information can be sent to a file. The Code V Converter Utility in OptiTools can be used to convert the output file from Code V to another format that Optiwave can read as input to the beginning of a waveguide. Optiwave applications can analyze the subsequent waveguide part of the system, and estimate the coupling loss on input. If the light needs to leave the waveguide and re-enter a lens system, the Code V converter can convert the output near-field-pattern to a form that Code V can accept as input to a ray tracing problem.

To access the Code V converter, select it from the OptiTools dialog box (Figure 1), and click Run... to get the CODE V Converter dialog box

CODE V ==>OptiBPM specifies conversion from CODE V format to Optiwave format

OptiBPM ==>CODE V specifies conversion from Optiwave format to CODE V format

Note that Code V keeps wavelength information, but Optiwave does not. Therefore, on converting from Optiwave to Code V it is necessary to supply this information in the enabled Wavelength field

Wavelength (nm) wavelength parameter stored in the CODE V file
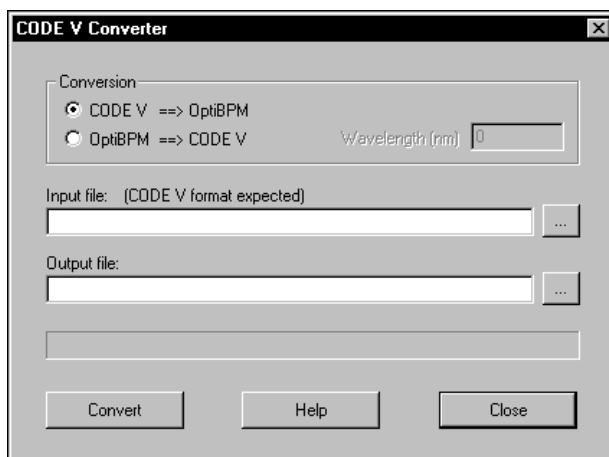
Figure 25: Code V Converter dialog box

Input File Enter or browse to the file to convert. It must be of the expected format

Output file Enter the name of the file to hold the converted data.

The data format for the OptiBPM compatible file is the standard Optiwave .f3d file format (see Appendix A - Optiwave File Formats for file definitions). The information from Code V is contained in a text file with the default file extension .dat. Any line starting with an exclamation (!) is a comment. The file may start with any number of comments. The next several lines contain information about the data. Each of these lines begins with a label describing the information on the line. The label ends with a colon (:). The information pertaining to the label follows the colon. White space (at least two spaces) will appear between the colon and the following data item and between the data items on the line. These may appear in any order. It is assumed that the first row that is not a comment (starts with a !) or a label (contains a colon) is the first row of data.

The labels are currently defined as follows:

Label	Definition
Datatype	Type of data
Wavelength	wavelength units
Grid spacing	x-spacing, y-spacing units
Array size	x-size, y-size
Coordinates	x, y, z units
Direction	l m n

Datatype may be Complex or Real. Units are specified as two-character mnemonics, as shown in the following table:

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nm   nanometers
mm   millimeters
cm   centimeters
in   inches

Coordinates are the (x,y,z) coordinates of the center of the grid with respect to a reference surface. The direction is the set of direction cosines (l,m,n) defining the direction of the beam with respect to the reference surface. Both of these are optional and would normally be (0,0,0) and (0,0,1).

An example of a Code V file is shown below:

```
! CODE V      Real optical field data
Datatype      Real
Wavelength    1550.0 nm
Grid spacing  .00013; .00013 mm
Array size    4 x 4
.27   .36e0   .39   2.1e-1
.45   .76     .78   .59
.35   .49     .55   .46
.12   .34     .67   7.45
```

The optical field data follows the header information. All the optical field data is assumed to lie on a regular grid specified by the grid spacing and grid size. Many of the calculations in CODE V assume that the grid is square and the grid size is a power of 2 (for example, 32, 64, 128,). However, this is not universal, so both the X and Y grid spacings and sizes are specified. All of the data is in a spreadsheet type of format and may be space delimited (single space) or tab delimited (it is designed to be imported/exported into Microsoft Excel). Therefore, all the values for a single row must be on the same line. The data may be in integer, fixed-decimal, or floating-point format.

In the example shown above, the first line is a comment. The second line specifies that this is real data (e.g., field intensity), so there is one value per grid point. The third line gives the wavelength and the units. The example above uses nanometers for the units, but other units may be used as long as they are specified. The fourth line gives the X and Y grid spacings and the units. The fifth line gives the X and Y arrays sizes. Note that numbers may be integer, fixed-decimal, or floating-point notation, and they may be mixed. Spaces or tabs are used to separate adjacent numbers. The data starts on the line following the last label. If M and N are the X and Y array sizes, there must be M numbers in each row and N rows of data. The coordinate convention used is that the origin is in the center of the grid and the upper right hand quadrant is (+X,+Y). The optical axis is the Z axis, and the light travels in the +Z direction. The observer is looking towards the source of the light (the opposite direction of the light propagation).

The data for a complex array looks very similar, except that two adjacent

numbers, real and imaginary, are included for each grid point. Thus, for a 4 x 4 grid, there are 4 rows each containing 8 numbers.

11 EXFO OWA Converter

The OWA converter is a software module used to convert files created by the EXFO OWA 9500 Optical Waveguide Analyser into Optiwave file format. The EXFO instrument is used to scan the refractive index of a waveguide facet at a specific wavelength, 656nm. The results of the scan are stored in an EXFO proprietary format within a file. The OWA Converter translates the data into an Optiwave refractive index data file so that the waveguide can be numerically analyzed within the Optiwave mode solver. Apart from the data format transformation, the converter has two additional functions

- The OWA converter enables approximation of the refractive index distribution at a user specified wavelength, which may be different from the wavelength the OWA instrument uses for the measurement of refractive index in the index profile scanning.

- The OWA converter allows the original index scan mesh and window to be changed. This function is necessary because the observation window and mesh used in the measurement is often not convenient for calculation. To perform successful modal analysis, the waveguide facet observation window may need to be clipped or extended, and the mesh may need to be adjusted to a finer or more coarse level.

11.1 Region Selection and Expansion

Selected Region panel The grey rectangle in the centre of the viewing region will be exported. Use the mouse to move or extend the rectangle, or enter the coordinates directly into the fields in the Selected Region panel. Choosing an area smaller than the view display will clip the measured data out of the calculation.

Data Points In Selected Region panel The integers in the read only fields in this panel indicate the number of data points of the original data set that are enclosed by the selected rectangle. This number will give some idea regarding the accuracy of the interpolation.

Final Mesh Size panel Use these fields for adjusting the mesh of the new file to the desired level. Since the new mesh does not coincide with the old one, the new mesh points are assigned on a nearest-to-original-mesh-point basis. In this simple algorithm depicted in the figure below, the closest original mesh point defines the refractive index on the new mesh.
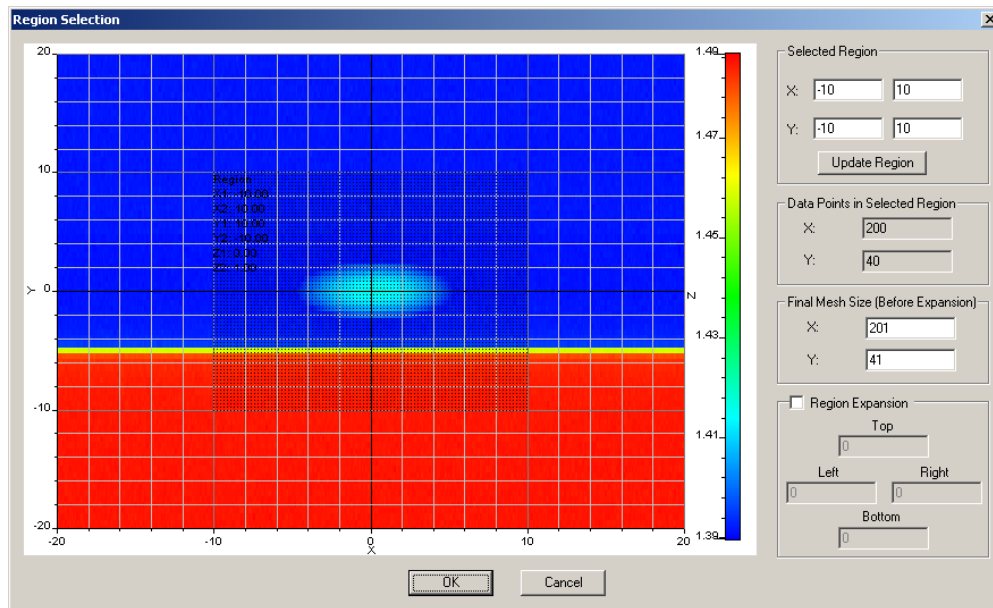
Figure 26: Region Selection and Expansion

Region Expansion panel If the original refractive index measurement was done over a region too small to hold the optical field, it will be necessary to extend the data beyond the original boundaries. This situation might occur in a waveguide measurement with low index contrast. The measurement is concentrated in the area of the waveguide, but the field extends far into the cladding. Some simple form of extrapolation is desirable. Figure 28 describes how the extrapolation is done.
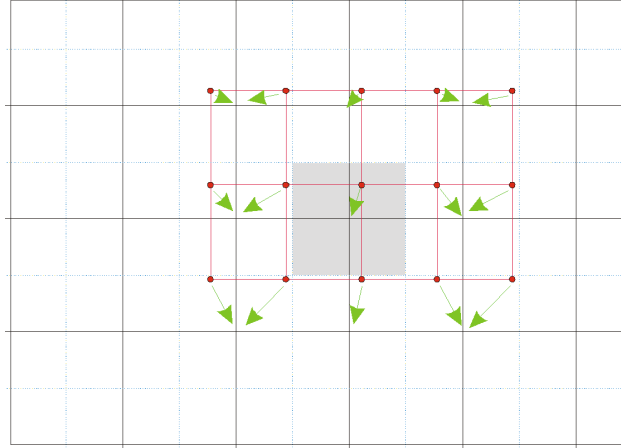
Figure 27: Original mesh (black) is different from the new mesh (red). The values on the red mesh are defined by the closest 'black' mesh point.
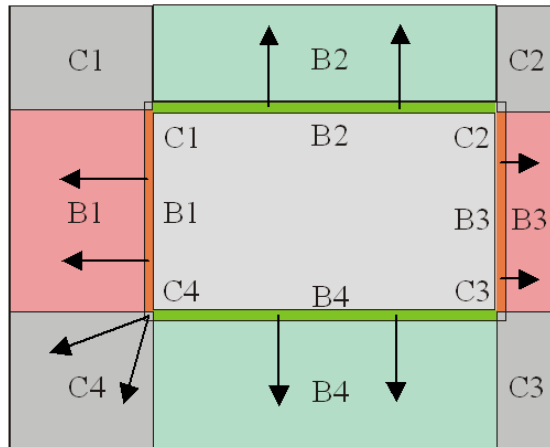
1	1	1	1	5	4	6	6	6
1	1	1	1	5	4	6	6	6
1	1	1	1	5	4	6	6	6
2	2	2	2			8	8	8
3	3	3	3	4	5	7	7	7
3	3	3	3	4	5	7	7	7
3	3	3	3	4	5	7	7	7
3	3	3	3	4	5	7	7	7

Figure 28: Expansion of the region. The inner grey rectangle is exported on a larger domain (outer rectangle on the left). The unknown values outside the measured boundary are filled up with the boundary values as shown. B1, B2, B3 and B4 are value arrays of the refractive index on the horizontal and vertical boundaries, C1C4 are single values of the refractive index in the corners of the the scanned domain. An example of the expansion is shown on the right. The Grey shaded region is the last boundary layer of the original scanned data.

11.2 Wavelength Extrapolation

This is an optional step. To perform the extrapolation from the measurement wavelength to another (working) wavelength, go to the OWA Converter dialog box. In this dialog, select the Sellmeier Extrapolation check box. Then click on Parameters, to open the Sellmeier Parameters dialog box, as shown in Figure 29
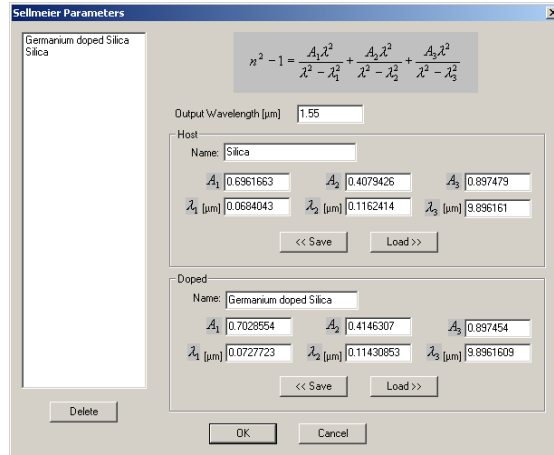
Figure 29: Sellmeier Parameters dialog box

Host Panel Select a material (e.g. Silica) in the library list in the window on the left. Click on Load to load the Silica parameters into the Host Panel. Alternatively, this panel can be used to create a new material in the library. To do this, enter the appropriate numbers in the fields, enter a new (unique) name, and click Save. Once created, these parameters can be later recalled as described above, by selecting the library name and clicking on Load.

Doped Panel This panel works the same way as the Host Panel, but it enters the algorithm in a different place. See the discussion below for the details.

Output Wavelength The wavelength at which the waveguide will be used. In general, this is different from the wavelength used by the OWA 9500 instrument when it makes the measurement. See the following discussion for details on how this number is used in the algorithm.

The terminology used in the dialog boxes (namely host, doped) is taken from optical telecommunication fibers. The fibres are often made from silica glasses. The high purity glass is called the host material or substrate. Its bulk refractive index is usually the fiber cladding refractive index. To change the refractive index of a material, the material can have dopants added to it. For example,

adding germanium to pure silica can result in an increase in the refractive index, while adding fluorine reduces it. The refractive index of doped material can be determined by the linear relationship between the doped material's mole percentage and permittivity.

Assume that n_0 is the refractive index of the host material and n_1 is the refractive index of m_1 mole-percentage doped material. Then, the refractive index n of m mole-percentage doped material can be interpolated as:

$$n^2 = n_0^2 + \frac{m}{m_1}(n_1^2 - n_0^2) \tag{26}$$

The square of the index and not the index itself is linearly interpolated. The model assumes that the dopants contribute to the electric displacement $\mathbf{D}$ in response to an applied field $\mathbf{E}$ in proportion to the mole fraction of the dopant. The coefficient of proportion of $\mathbf{D}$ to $\mathbf{E}$ is the permittivity, proportional to n^2. Note that this formula can also extrapolate (the case where $m > m_1$). When the refractive index at a central wavelength λ_0, $n(\lambda_0)$, and the host and dopant material dispersion curves, $n_{host}(\lambda_0)$ and $n_{dopant}(\lambda_0)$ are defined, the dependence of the refractive index with wavelength, , is calculated based on the following equation:

$$n^2(\lambda) = n_{host}^2(\lambda) + \frac{n^2(\lambda_0) - n_{host}^2(\lambda_0)}{n_{dopant}^2(\lambda_0) - n_{host}^2(\lambda_0)}[n_{dopant}^2(\lambda) - n_{host}^2(\lambda)] \tag{27}$$

This equation is the same as equation (26), with the fraction m/m_1 estimated by comparing, at the reference wavelength λ_0, the refractive index of the given material with the index of a doped material with known Sellmeier coefficients (n_{dopant}). OWA Converter uses Equation (27) to handle the case where the Sellmeier coefficients are known for material of just one doping concentration. If the material in question has the same dopant, but with an unknown concentration, the fraction in Equation (27) will estimate the concentration by comparing the given index $n(\lambda_0)$ with the reference index $n_{dopant}(\lambda_0)$. With the doping concentration estimated this way, the refractive index at other wavelengths is accurately estimated by equation (27).

The functions $n_{host}(\lambda)$ and $n_{dopant}(\lambda)$ are often one of the Sellmeier formulas. For example, the following 3 term formula is suitable for fused silica throughout the wavelength range 0.21 to 3.71 microns

$$n^2 - 1 = \frac{A_1\lambda^2}{\lambda^2 - \lambda_1^2} + \frac{A_2\lambda^2}{\lambda^2 - \lambda_2^2} + \frac{A_3\lambda^2}{\lambda^2 - \lambda_3^2} \tag{28}$$

where

$$A_1 = 0.6961663$$
$$A_2 = 0.4079426$$
$$A_3 = 0.897479$$
$$\lambda_1 = 0.0684043$$
$$\lambda_2 = 0.1162414$$
$$\lambda_3 = 9.896161$$

Wavelength dependent measurements on a sample of silica with some fixed level of doping can be used to fit to an equation of form (28), to get slightly different values of the As and λs. These 12 values are used to define the functions $n_{host}(\lambda)$ and $n_{dopant}(\lambda)$ in Equation (27). You can create named entries with 6 parameters associated with each name. Use the Save and Load buttons to build a library containing parameters suitable for your material system. The values are remembered the next time the application is called. Typical library entries for various silica materials are supplied by Optiwave in the initial installation.

In the operation of the EXFO OWA-9500, the measurement wavelength is $\lambda_0 = 656$nm. The refractive index measured at this wavelength at a given point is squared and it takes the place of $n^2(\lambda_0)$ in Equation (27). The desired wavelength (the contents of the Output Wavelength Field) is set to λ in Equation (27), and the index of the material at the output wavelength is evaluated from the formula. The same process is repeated at each point in the raster scan to develop a refractive index profile as would be seen by the long wavelength.

12   Zemax Converter

Optiwave supplies simulation software for waveguide optics, and is optimized for analysis of structures that are of size (in the transverse plane) comparable to an optical wavelength. Although it is theoretically possible to analyze free space or bulk optical components such as lenses and mirrors by the solution of Maxwells equations, generally it is more practical to make use of approximations commonly used in ray optics. Optiwave does not supply ray optics software, but OptiTools has a utility to convert the data of another software, Zemax. With Zemax, one can analyze bulk optics such as mirrors and lenses using ray tracing, Zemax can be used together with Optiwave to analyze the whole system. Zemax can use ray tracing to determine the optical field distribution at the focal point, and the information can be sent to a file. The Zemax Converter Utility in OptiTools can be used to convert the output file from Zemax to another format that Optiwave can read as input to the beginning of a waveguide. Optiwave can analyze the subsequent waveguide part of the system, and estimate the coupling loss on input. If the light needs to leave the waveguide and re-enter a lens system, the Zemax converter can convert the output near-field-patter to a form that Zemax can accept as input to a ray tracing problem.

To access the Zemax converter, select it from the OptiTools dialog box (Figure 1), and click Run... to get the Zemax Converter dialog box
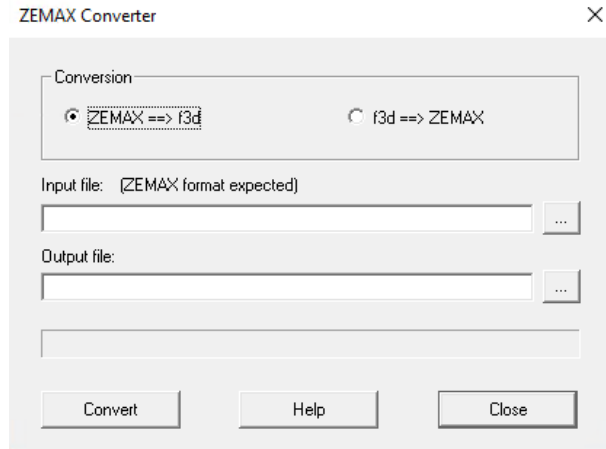
Figure 30: Zemax Converter

12.1 Conversion

ZEMAX ==>f3d specifies conversion from ZEMAX format to Optiwave f3d format. These are mutually exclusive options. Specify the direction of conversion. ZEMAX ==>f3d is selected by default.

f3d ==>ZEMAX specifies conversion from Optiwave format to ZEMAX

Input File (ZEMAX format expected): displays the name of input file. Editable text field. Empty by default. Specifies the path and name of the input file. May be filled in through the browser button located to the right of it, which displays a Windows standard file open dialog. In this dialog the user will be able to filter filenames according to typical extensions for the file formats (*.f3d for Optiwave and *.zbf for ZEMAX). Click Browse to load a file from a folder.

Output file displays the name of the output file. Editable text field. Empty by default. Specifies the path and name of the output file. May be filled in through the browser button located to the right of it, which displays a Windows standard file save dialog. In this dialog the user will be able to filter filenames according to typical extensions for the file formats (*.f3d for Optiwave and *.zbf for ZEMAX). Click Browse to load a file from a folder.

12.2   Notes on Conversion

The ZEMAX file has Nx powers of two only, and Optiwave can have any integer. The difference is made up by using the next power of two in the ZEMAX file, and adding zeros in the new space in the ZEMAX file to keep the data of Optiwave in the middle of mesh. When converting back from ZEMAX to Optiwave, the added zero points are not removed. The Optiwave file can have Nx and Ny either even or odd. in the case of odd number, the mesh of ZEMAX and Optiwave cannot be made to overlap exactly. The zero padding on the plus side of the axix will have one more point in it than on the minus side. This changes the position of the centre of the field by half a mesh point.

The unit in Optiwave is always microns, but the unit of microns is not a possible unit in the ZEMAX file. Therefore, on conversion to ZEMAX file, distances in microns are converted to mm, and the units are set to mm. In converting the other way, distances are converted into microns. This means that applying the conversion twice (there and back again) could generate a result in different units from the original.

There are several parameters defined in the ZEMAX file that dont exist in the Optiwave file. These are zx, Rx, zy, Ry, wy, lambda, index, re, and se. On converting from Optiwave to ZEMAX, all these parameters are set to zero. The settings of these variables in the global scope will be used in the ZEMAX project.

On converting from Optiwave to ZEMAX, Dx=(Xmax-Xmin)/Nx-1, Dy=(Ymax-Ymin)/Nx-1. On converting from ZEMAX to Optiwave, Xmax=Dx*(Nx-1)/2, Xmin=-Xmax, Ymax=Dy*(Ny-1)/2, Ymin=-Ymas. so when we convert back and forth, the Ymin/Ymax and Xmin/Xmax may be changed.

12.3   Data formats

This converter can read the Optiwave file in the format BCF3DPC, BCF3DCX, BCF3DCX 3.0 and BCF3DCX, and convert it to the ZEMAX file in binary format. If the Optiwave file is in BCF3DCXV format, then the target ZEMAX file will be set to polarized. These data formats for the Optiwave compatible file have extension .f3d (see Data file formats in Appendix A for definitions). The information from Zemax is contained in a binary file. This converter can only read the ZEMAX file in binary format. Optiwave doesn't support the ASCII format ZEMAX file. If the is polarized is set (1), then the converter will create an Optiwave file in BCF3DCXV format, otherwise it always creates the Optiwave file in BCF3DCX 3.0 format.

12.4   ZEMAX Beam File (ZBF) binary format

Beams in ZEMAX are always centered on the chief ray for the selected field and wavelength. Therefore, the data in the beam file should be positioned relative to the chief ray that will be used to align the beam. The center point in the beam file is at the coordinate (nx/2+1, ny/2+1). ZEMAX requires the values

of nx and ny to be an integral power of 2; for example, 32, 64, 128, 256, etc. The minimum sampling is 32 and the current maximum sampling is 8192. Fiber coupling data is ignored when reading beams, and will be zero if fiber coupling is not computed on output. Note the total fiber coupling is the product of the receiver and systems efficiency. The first data point is at the -x, -y corner, and the data proceeds across the x rows first. The Rayleigh distance is ignored on input and is automatically recomputed by ZEMAX. The wavelength value stored in ZBF file is scaled by index of the media the beam is curently in.

The ZBF binary file format is defined as follows. All integers are 4 bytes, all doubles are 8 bytes.

1 integer:	The format version number, currently 1.
1 integer:	The number of x samples (nx).
1 integer:	The number of y samples (ny).
1 integer:	The "is polarized" flag; 0 for unpolarized, 1 for polarized.
1 integer:	Units, 0 for mm, 1 for cm, 2 for in, 3 for meters.
4 integers:	Currently unused, may be any value.
1 double:	The x direction spacing between points.
1 double:	The y direction spacing between points.
1 double:	The z position relative to the pilot beam waist, x direction.
1 double:	The Rayleigh distance for the pilot beam, x direction.
1 double:	The waist in lens units of the pilot beam, x direction.
1 double:	The z position relative to the pilot beam waist, y direction.
1 double:	The Rayleigh distance for teh pilot beam, y direction.
1 double:	The waist in lens units of the pilot beam, y direction.
1 double:	The wavelength in lens units of the beam in the current medium.
1 double:	The index of refraction in the current medium.
1 double:	The receiver efficiency. Zero if fiber coupling is not computed.
1 double:	The system efficiency. Zero if fiber coupling is not computed.
8 doubles:	Currently unused, may be any value.
2*nx*ny double:	Ex values.

13   Matrix Converter

Optical and refractive index data is stored in a single column of real or complex numbers. The Matrix Converter can change the representation such that the data will be stored as rows and columns, with the rows following the X coordinate and the columns following the Y coordinate.

To use the Matrix converter, select it from the OptiTools dialog box (Figure 1), and click Run... to get the Data Transformer dialog box, Figure 31.

Styles Select Matrix with dimensions header to get the dimension information at the top of the file. Select Matrix with coordinates to get the X and Y coordinates in the first row and first column
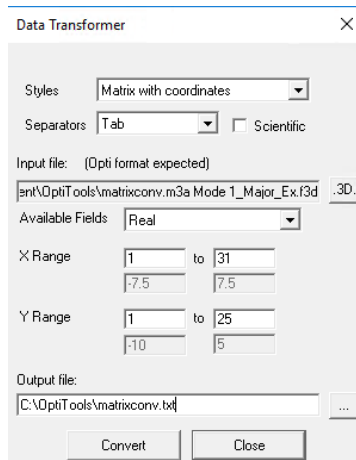
Figure 31: Data Transformer dialog box in support of Matrix Converter

Separators select tab or space to separate the data numbers in the rows

Input File click .3D button to browse to the Optiwave format file with all data in one column

Available Fields select the desired complex component

XRange, Y Range select the desired ranges of data to go to Output file

Output file path and file name of the data file where the converted data will be put.

14 Mesh Converter

In using Optiwave software, it is sometimes necessary to change the mesh on which optical data is stored. For example, meshing requirements in the FDTD method are different from the requirements on a mesh for simulation by BPM. The mesh from the FDTD simulation might be oversampled for a BPM simulation, and vice versa. For example, in Figure 32, the crossed waveguides might have been simulated with an FDTD method, but the longer waveguides might have been simulated by BPM. At the junction between the simulation zones, it will be necessary to move optical data from a mesh suitable for BPM to one suitable for FDTD, and vice versa.

The Mesh Converter tool is used to take optical data on one mesh and to represent it on another mesh. The new mesh could have a different number of mesh points, and the window could be of a different size and position.

To use the Mesh converter, select it from the OptiTools dialog box (Figure 1), and click Run... to get the Mesh Converter dialog box, Figure 33
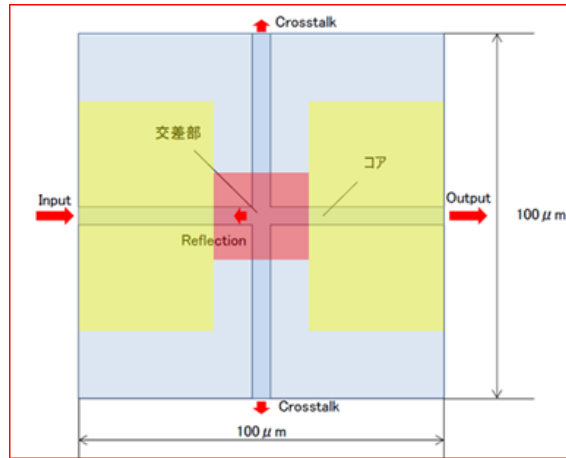
Figure 32: A simulation using both FDTD (red square) and BPM (yellow rectangles).

Input File path and file name of optical data on one mesh and coordinate system.

Original Data display of the mesh, window, and coordinate system of the optical data in the Input File

Shift enter a displacement to be applied to the origin of the coordinate system

Domain enter the window dimensions to be applied to the new, resampled optical data

Mesh Points enter the number of mesh points to be applied to the resampled optical data

Output File the path and file name of the new, resampled optical data

Note: points which are outside of the region of the original field will appear as zero in the Output File.

Figure 33: Mesh Converter dialog box

15   Appendix A - Optiwave File Formats

15.1   Generic file format

The Generic file format is a text format that consists of three data columns, X, Y, and Z, separated by space. This format is one of the export formats. It is not supported by any of the viewers.

```
X   Y   Z
1   1   1
2   2   2
...
N   N   N
```

15.2   Real Data 2D File Format: BCF2DPC

Applies to input and output files that contain real data as text. The file contains the file header, number of data points, and the real x and y data points:

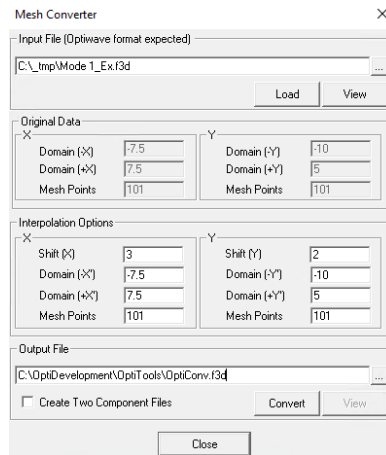|		
BCF2DPC		file header (this string is used to identify the file type)
N		number of data points
X1	Y1	first x and y data separated by space
X2	Y2	second x and y data separated by space
...		

Files that follow the BCF2DPC format:

- Output files in BPM 2D: [*.rpd], [*.poi]

- Output files in BPM 3D: [*.rpd], [*.poi]

Example: Power overlap integral output file in BPM 2D [.poi]*
    In this example, a Gaussian input field is propagated in a Linear Waveguide from the starting distance 0.000000E+000 to the end distance 1.000000E-001. The propagating field is overlapped with the starting field, giving the power overlap value 1.000000E+000 at the start and the value 4.034535E-001 at the end of propagation. The number of displays in the Global Data dialog box is 30, while the actual number of saved data points is 31. This is, because the file contains also the power overlap value at the start of propagation in addition to 30 values from the propagation.

```
BCF2DPC                                file header
31                                     number of data points
0.000000E+000    1.000000E+000         start distance and power overlap at start
3.330000E-003    3.558430E-001         distance and power overlap
6.670000E-003    3.663763E-001         distance and power overlap
9.333000E-002    4.039581E-001         distance and power overlap
9.667000E-002    4.038129E-001         distance and power overlap
1.000000E-001    4.034535E-001         end distance and power overlap
```

15.3 Real Data 3D File Format: BCF3DPC

This format applies to input and output files that contain real data as text. The file contains the file header, number of x and y data points, minimum and maximum values of x, y and z, and the real z(x,y) data points. The data points are presented in one column with the order determined by scanning the x and y coordinates.

```
BCF3DPC             file header
NX         NY       number of x and y data points
XMIN       XMAX     minimum and maximum x values
YMIN       YMAX     minimum and maximum y values
ZMIN       ZMAX     minimum and maximum z values
Z1                  real z data point with coordinates (xmin, ymin)
Z2                  real z data point with coordinates (xmin+dx, ymin)
Z3                  real z data point with coordinates (xmin+2dx, ymin)
...
ZNX                 real z data point with coordinates (xmax, ymin)
ZNX+1               real z data point with coordinates (xmin, ymin+dy)
...
...
ZN                  last real z data point with coordinates (xmax, ymax), where N=NXxNY
```

In the above, the distance between mesh points is calculated from

$$dx = \frac{XMAX - XMIN}{NX - 1} \tag{29}$$

and

$$dy = \frac{YMAX - YMIN}{NY - 1} \tag{30}$$

Files that follow the BCF3DPC format:

- Output files in BPM 2D: [*.amp], [*.rri]

- Output files in BPM 3D: [*.rri], [*.poi] [*-x.amp]

15.3.1   Example: Real refractive index in BPM 2D [*.rri]

In this example, the transverse mesh extends from -5.000000E+000 to 5.000000E+000
microns. The propagation distance extends from 0.000000E+000 to 1.000000E-
001 millimeters. A Linear Waveguide with refractive index 1.5 is laid out on a
wafer with the index 1.3. The number of mesh points is 100 and the number of
displays in the Global Data dialog box is 30. The actual y number of saved index
x distributions is 31. This is because the file contains also the index distribution
at the start of propagation in addition to 30 values from the propagation.

BCF3DPC	file header
100 31	number of x and y data points
-5.000000E+000 5.000000E+000	minimum and maximum transverse wafer coordinates
0.000000E+000 1.000000E-001	minimum and maximum distance
0.000000E+000 1.000000E+000	unused values added by BPM 2D to conform to the format Note: OptiBPM adds a line of default values 0 and 1 to conform to this format.
1.300000E+000	real z data point with coordinates (xmin, ymin)
1.300000E+000	
...	
1.300000E+000	

15.4   Complex Data 2D File Format: BCF2DCX

This format applies to input and output files that contain complex number data
as text. The file extension will be .f2d. The file contains the file header, number
of data points, mesh width, and the complex z data points:

BCF2DCX 3.0	file header
N	number of data points
Xmin Xmax	minimum and maximum x values
Z1	first complex data point
Z2	second complex data point
...	
ZN	last complex data point

15.5   Complex Data 3D File Format: BCF3DCX

This format applies to input and output files that contain complex data as text.
The file contains the file header, number of x and y data points, window widths
in x and y, and the complex z(x,y) data points. The data points are presented
in one column with the order determined by scanning the x and y coordinates.
These files will have extension .f3d

BCF3DCX 3.0	file header
NX NY	number of x and y data points
Xmin Xmax Ymin Ymax	minimum and maximum x and y values
Z1	complex number z data point with coordinates (xmin, ymin)
Z2	complex number z data point with coordinates (xmin+dx, ymin)
Z3	complex number z data point with coordinates (xmin+2dx, ymin)
ZNX	complex number z data point with coordinates (xmax, ymin)
ZNX+1	complex number z data point with coordinates (xmin, ymin+dy)
...	...
ZN	last complex number z data point with coordinates (xmax, ymax), N=NXxNY

15.6   Complex Data 3D Vectorial File Format: BCF3DCXV

This format applies to input and output files that contain vectorial complex data. The file contains the file header, number of x and y data points, mesh widths in x and y, and the complex z(x,y) data points both for Ex and Ey field components. The data points are presented in one column with the order determined by scanning the x and y coordinates.

BCF3DCXV	file header
Nx Ny	number of x and y mesh points
Xmin Xmax Ymin Ymax	minimum and maximum X and Y coordinates
Za1	complex field (Ex field component) at point with coordinates (xmin, ymin)
Za2	complex field (Ex field component) at point with coordinates (xmin+dx, ymin)
Za3	complex field (Ex field component) at point with coordinates (xmin+2dx, ymin)
...	
ZaNX	complex field (Ex field component) at point with coordinates (xmax, ymin)
ZaNX+1	complex field (Ex field component) at point with coordinates (xmin, ymin+dy)
...	
ZaN (N=Nx*Ny)	complex field (Ey field component) at point with coordinates (xmax, ymax)
Zb1	complex field (Ey field component) at point with coordinates (xmin, ymin)
Zb2	complex field (Ey field component) at point with coordinates (xmin+dx, ymin)
Zb3	complex field (Ey field component) at point with coordinates (xmin+2dx, ymin)
...	
ZbNX	complex field (Ey field component) at point with coordinates (xmax, ymin)
ZbNX+1	complex field (Ey field component) at point with coordinates (xmin, ymin+dy)
...	
ZbN (N=Nx*Ny)	complex field (Ey field component) at point with coordinates (xmax, ymax)

Note: The total number of data points is twice the number of the total mesh points Nt=2*N.

15.7   Non-uniform Mesh

Sometimes optical data is defined on a non-uniform mesh. In these cases, two other files are employed to specify the coordinates of the mesh points. One file specifies the coordinates (in microns) of the X mesh points, the other the coordinates of the Y mesh points.

These files should consist of numeric values representing the position in micrometers separated by new lines. The numeric values should start at the minimum position and finish at the maximum position as demonstrated below:

-3.5000000e-001

-3.2875000e-001

-3.0750000e-001

-2.8625000e-001

...

2.8625000e-001

3.0750000e-001

3.2875000e-001

3.5000000e-001

This example file represents a mesh starting at -0.35 microns and ending at 0.35 microns. The actual file contains 61 mesh points and is shortened here. The file extension normally used is ".txt", however any extension can be used. When using a file with Optiwave software it is important to match the minimum and maximum position value to those stated in the software, for example in OptiFDTD the file extrema values should match the wafer size in the Designer.

15.8   User Refractive Index Distribution File Format

UPI2DRI 3.0	file header
NPM	number of points in mesh
XMIN XMAX	min and max mesh points
Z1	first complex number data point
Z2	second complex number data point
..	
ZN	last complex number data point

15.9   Path Monitoring File Format

In OptiBPM, there is a feature to monitor the optical power in waveguides during propagation. This is known as Path Monitor. The data from these monitors can be exported, it comes in this format. The extension of the file is .mon.

BCF2DPM				file header
Npts Npath				Number of data points and number of paths
Distance	Path 1	.	NPath	text descriptor
Xcoord1	p1val1	...	pNval1	first value of paths
...				
XcoordNpts	p1valNpts	...	pNvalNpts	last value of paths

15.10   Power In Output Waveguides File Format

OptiBPM can calculate the Power in Output Wavegides. The exported file with
the data has extension.piw and it is in the following format:

BCF2DMC				file header
Npts N				Number of data points and number of output waveguides
Iteration	waveguide1	.	waveguideN	descriptive text
1	power1	...	powerN	power in each waveguide, first iteration
...				
Npts	power1	...	powerN	power in each waveguide, last iteration