Created in COMSOL Multiphysics 5.6

Focusing Lens

Introduction

It is challenging to simulate systems with optical lenses by the standard full vector wave analysis method because the number of mesh elements tends to be extremely large for the size of regular optical lenses. Since the standard frequency domain analysis solves for the electric field, the mesh needs to resolve the fast-oscillating field amplitude in order to get an accurate solution, that is, the maximum element size needs to be $1/5$ of the wavelength or smaller. This standard method is suited for systems that are comparable to or up to ten times the wavelength. Compared to the standard method, the beam envelopes method is another type of full vector wave analysis that solves for the slowly varying envelope. With this method, the requirement for meshing is largely reduced depending on how slowly the envelope varies and therefore it is possible to solve systems with a large domain size. Lenses that are relatively smaller in size and are slow (focal length is not too small) may potentially be good candidates for the Electromagnetic Waves, Beam Envelopes interface in the Wave Optics Module, if the intensity computation is of interest.

In this model, a plano-convex focusing lens is analyzed by using the Electromagnetic Waves, Frequency Domain interface and the Electromagnetic Waves, Beam Envelopes interface. The computational results are compared. The Electromagnetic Waves, Frequency Domain interface analyzes only the lens domain and its vicinity. A boundary field at the exit plane of the lens is propagated to the focal plane by the Fresnel diffraction formula. The Electromagnetic Waves, Beam Envelopes interface analyzes the entire domain including the focal plane.

Model Definition

The plano-convex lens has a diameter of $0.2\ \mathrm{mm}$, thickness of $15\ \mu\mathrm{m}$, the radius of curvature of $0.5\ \mathrm{mm}$, and the focal length of about $1\ \mathrm{mm}$. The front surface of the lens is illuminated by a top-hat beam with a size of $0.1\ \mathrm{mm}$, as depicted in Figure 1. This is a slow lens with a numerical aperture of about 0.05.

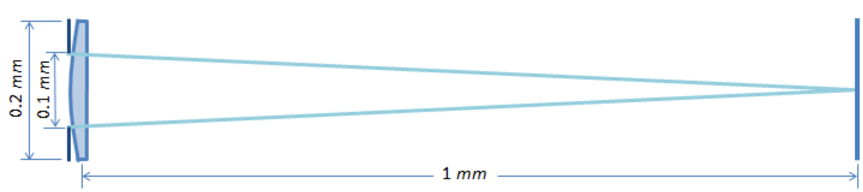


Figure 1: The optical layout.

The first study uses the Electromagnetic Waves, Frequency Domain interface to analyze the near field; that is, only the lens domain and its vicinity. After computing the near field, the electric field amplitude at the exit side of the lens is transformed to the focal plane by using the Fresnel diffraction formula (Ref. 1):

$$E(f, u) = \frac{1}{\sqrt{\lambda f}}\int_{-\infty}^{\infty} E(x_0, y)e^{-i\pi y^2/(\lambda f)}e^{i2\pi uy/(\lambda f)}dy$$

where λ is the wavelength; f is the focal length; and $u/(\lambda f)$ is called the spatial frequency; and $E(x_0, y)$ and $E(f, u)$ are the electric field amplitudes at the exit plane $x = x_0$ and at the focal plane $x = f$, respectively.

To evaluate the integral above, an integration operator `intop1` is defined on the boundary at the exit plane. The y coordinate in the focal plane, the coordinate u, is defined by a one-dimensional grid dataset. To make sure that u is evaluated on the grid data set, and not on the exit plane boundary, the `dest` operator is applied to u. The `dest` operator forces the expression that it operates on to be evaluated on the destination points (the grid data set points in this case) instead of the source points (the exit plane boundary). This means that the destination operator (`dest`) can be used to create convolution integrals and other integral transforms.

The second study uses the Electromagnetic Waves, Beam Envelopes interface to solve for the electric field norm in the entire domain, including the focal plane. In this simulation, it should be emphasized that the mesh element is as large as λ in the air domain, compared to the first study, in which the Electromagnetic Waves, Frequency Domain interface requires a mesh element of $\lambda/n/5$ everywhere in the near-field domain.

For both physics interfaces, a Transition boundary condition is used for approximating an anti-reflection (AR) coating applied to the lens surfaces. The Transition boundary condition has the advantage that the thin AR coating doesn't have to be represented, and thereby meshed, using a thin domain around the lens. Instead, the coating is approximated as a boundary condition.

For the Electromagnetic Waves, Frequency Domain interface, the Transition boundary condition is based on the assumption that the wave propagates in the normal direction to the boundaries within the thin AR coating layer. This is strictly not fulfilled in this model, but a good approximation as the waves propagate in directions quite close to the normal direction.

For the Electromagnetic Waves, Beam Envelopes interface, the Transition boundary condition is implemented either with the same assumption as described above or assuming that the waves propagate in the direction specified in the **Wave Vectors** section in the settings for the physics interface. In this model, the latter option is chosen, assuming it is a slightly better approximation than the first option.

The refractive index for the AR coating,

$$n_{AR} = \sqrt{n_{\text{Lens}}},$$

is specified in a material with a boundary selection. The thickness for the coating,

$$d_{AR} = \frac{\lambda}{4n_{AR}},$$

is specified in the Transition boundary condition nodes.

Results and Discussion

Figure 2 shows the result of the electric field amplitude in the computed near-field domain. The electric field amplitude at the exit plane (Figure 3) is transformed to the focal plane by using the Fresnel diffraction formula (Figure 4).

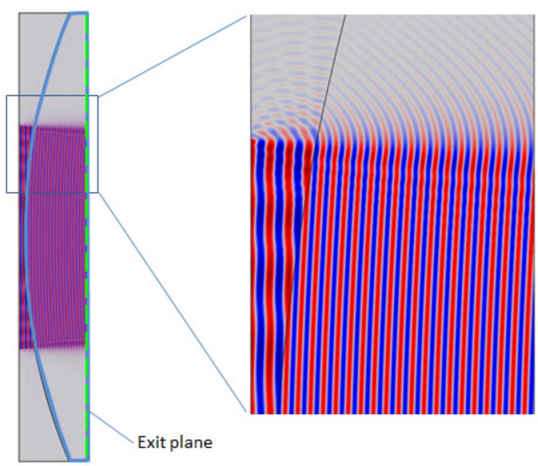


Figure 2: Electric field amplitude calculated in the near-field domain by using the Electromagnetic Waves, Frequency Domain interface. The aspect ratio is changed to 2:1.

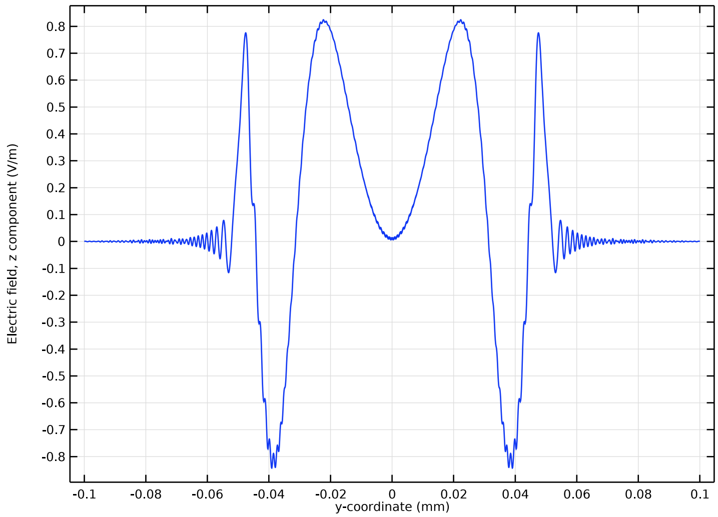


Figure 3: The electric field amplitude at the exit plane.

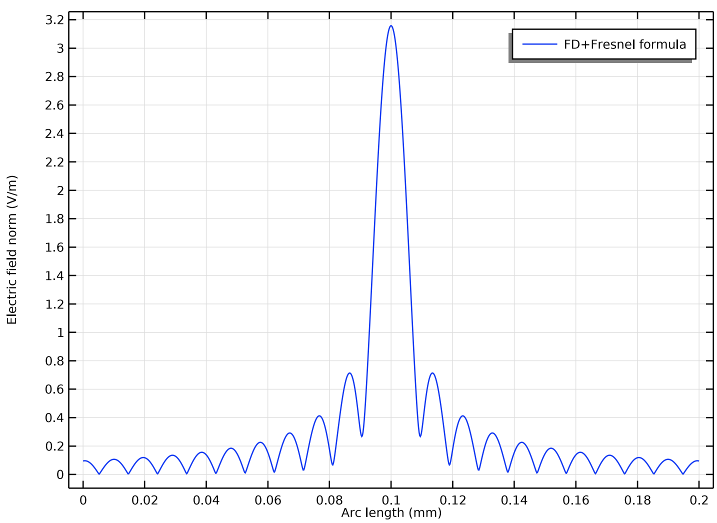


Figure 4: The norm of the transformed electric field at the focal plane.

Figure 5 is the electric field norm computed over the entire domain by using the Electromagnetic Waves, Beam Envelopes interface. Figure 6 compares the results of the electric field norm at the focal plane between the Electromagnetic Waves, Frequency Domain interface and the Electromagnetic Waves, Beam Envelopes interface. The two methods agree very well.

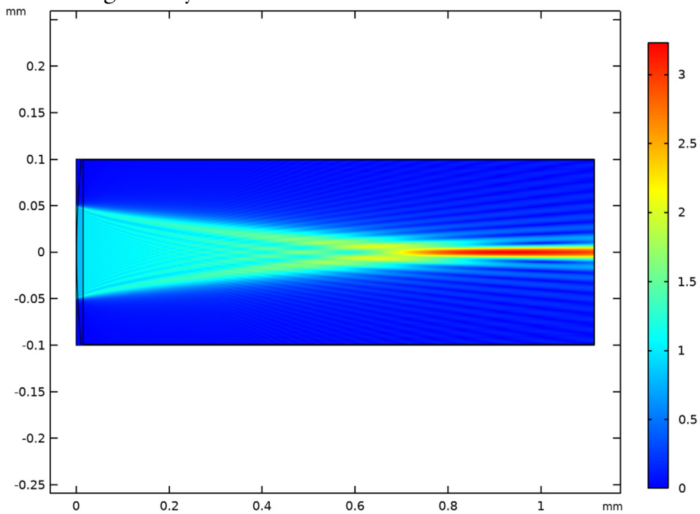


Figure 5: The electric field norm computed over the entire domain with the Electromagnetic Waves, Beam Envelopes interface.

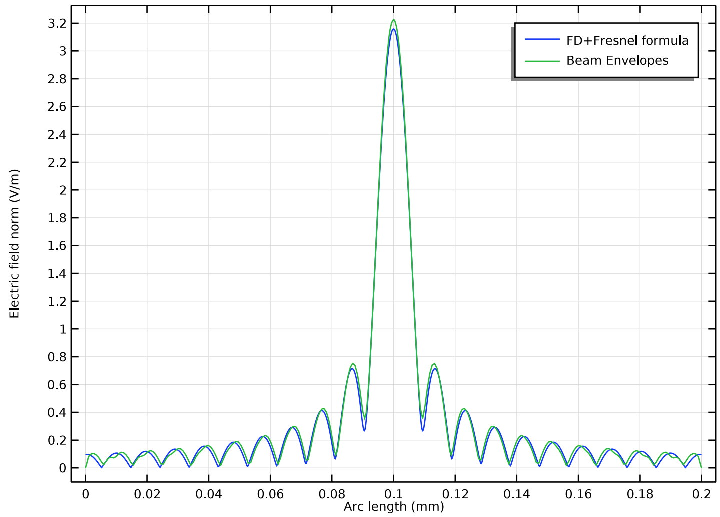


Figure 6: A comparison of the electric field norm at the focal plane between Electromagnetic Waves, Frequency Domain interface and Electromagnetic Waves, Beam Envelopes interface.

Reference

1. J.W. Goodman, *Introduction to Fourier Optics*, The McGraw-Hill Company, Inc.

Application Library path: `Wave_Optics_Module/Verification_Examples/focusing_lens`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **2D**.

2 In the **Select Physics** tree, select **Optics>Wave Optics>Electromagnetic Waves, Frequency Domain (ewfd)**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces> Wavelength Domain**.

6 Click **Done**.

GLOBAL DEFINITIONS

To save time, the parameters can be loaded from a file.

Parameters 1

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

2 In the **Settings** window for **Parameters**, locate the **Parameters** section.

3 Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `focusing_lens_parameters.txt`.

GEOMETRY 1

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Geometry 1**.

2 In the **Settings** window for **Geometry**, locate the **Units** section.

3 From the **Length unit** list, choose **mm**.

Rectangle 1 (r1)

1 In the **Geometry** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type `W_lens`.

4 In the **Height** text field, type `H`.

5 Locate the **Position** section. In the **y** text field, type `-H/2`.

Circle 1 (c1)

1 In the **Geometry** toolbar, click **Circle**.

2 In the **Settings** window for **Circle**, locate the **Size and Shape** section.

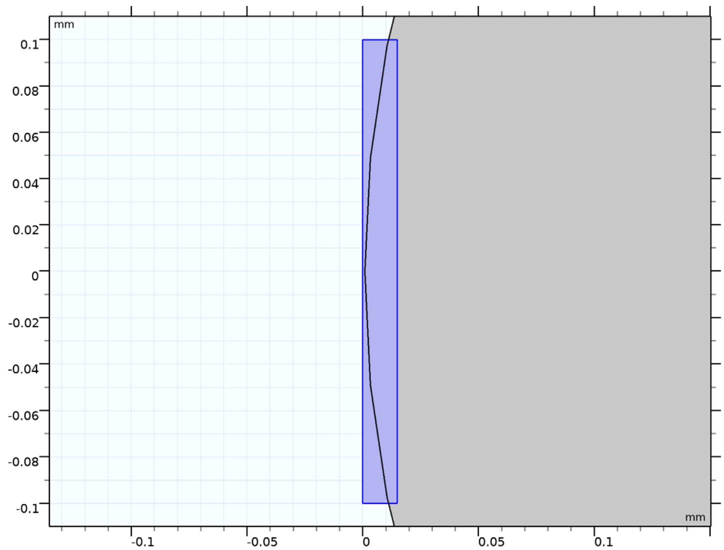
3 In the **Radius** text field, type `R`.

4 Locate the **Position** section. In the **x** text field, type `R+1[um]`.

Partition Objects 1 (par1)

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Partition Objects**.

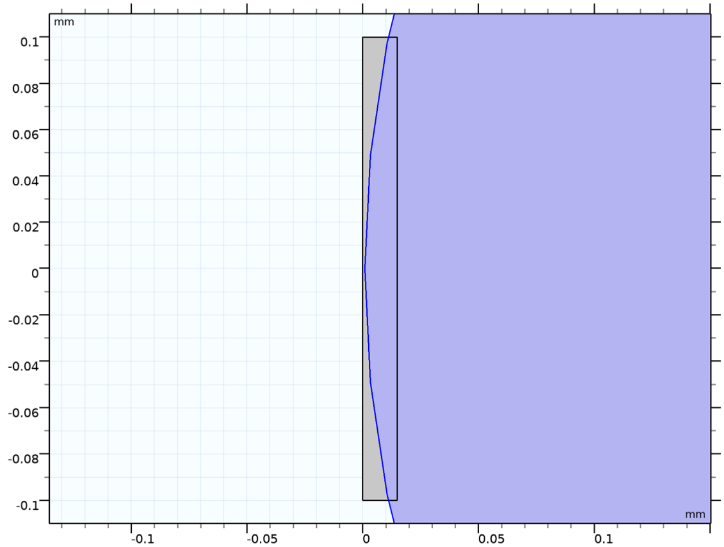
2 Select the object **r1** only.



3 In the **Settings** window for **Partition Objects**, locate the **Partition Objects** section.

4 Find the **Tool objects** subsection. Select the **Activate Selection** toggle button.

5 Select the object **c1** only.



Rectangle 2 (r2)

1 In the **Geometry** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type `W_air`.

4 In the **Height** text field, type `H`.

5 Locate the **Position** section. In the **x** text field, type `W_lens`.

6 In the **y** text field, type `-H/2`.

7 Click to expand the **Layers** section. In the table, enter the following settings:

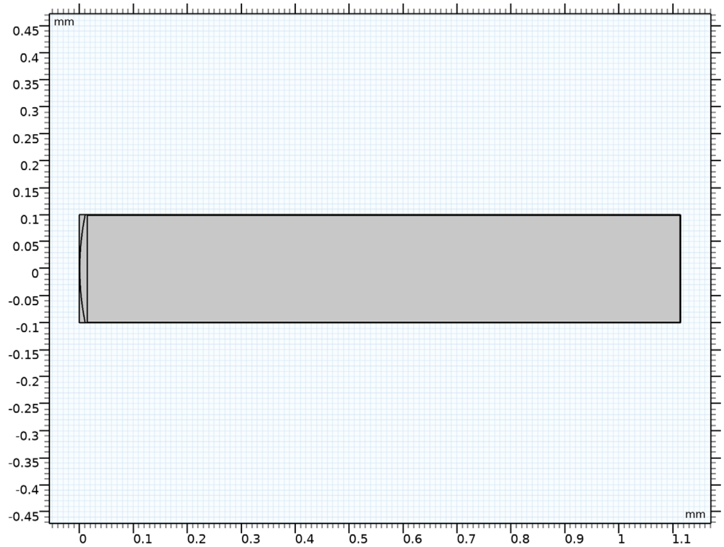
Layer name	Thickness (mm)
Layer 1	wl

8 Select the **Layers to the right** check box.

9 Select the **Layers on top** check box.

10 Click **Build All Objects**.

11 Click the **Zoom Extents** button in the **Graphics** toolbar.



DEFINITIONS

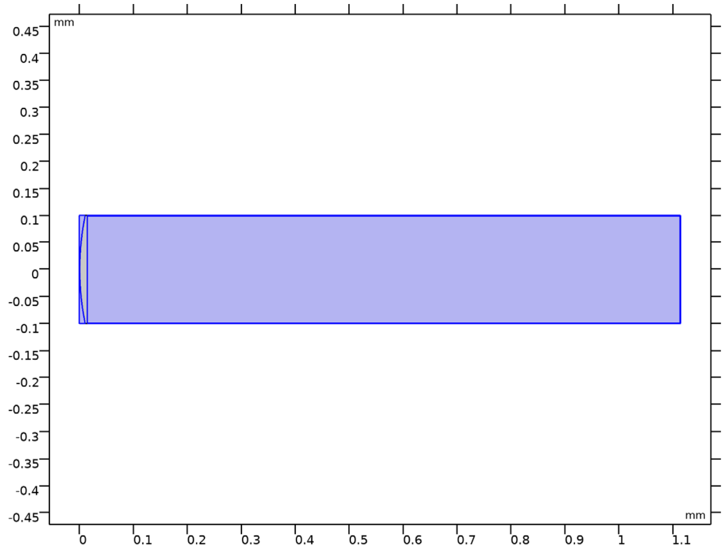
Before continuing, add a few selections for use later on in the modeling process.

Air

1 In the **Definitions** toolbar, click **Explicit**.

2 In the **Settings** window for **Explicit**, type `Air` in the **Label** text field.

3 Select Domains 1 and 3–8 only, by first enabling the **All domains** check box, then selecting entity 2 in the entity list, and finally clicking the **Remove from Selection** button.

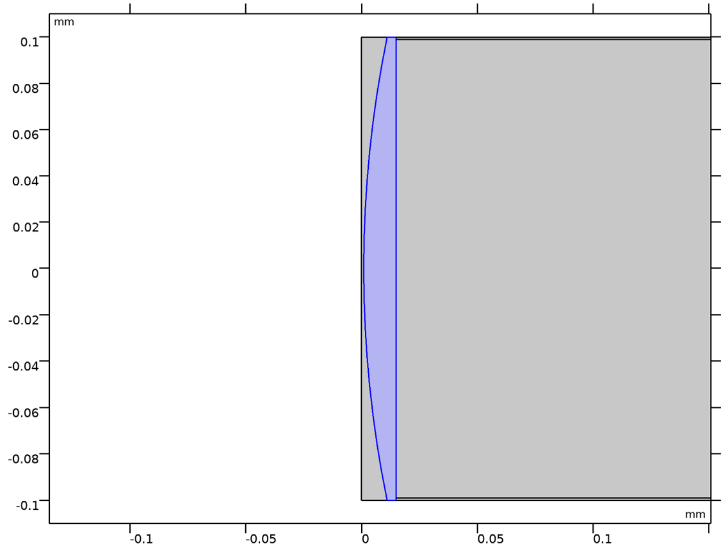


Lens

1 In the **Definitions** toolbar, click **Explicit**.

2 In the **Settings** window for **Explicit**, type `Lens` in the **Label** text field.

3 Select Domain 2 only.



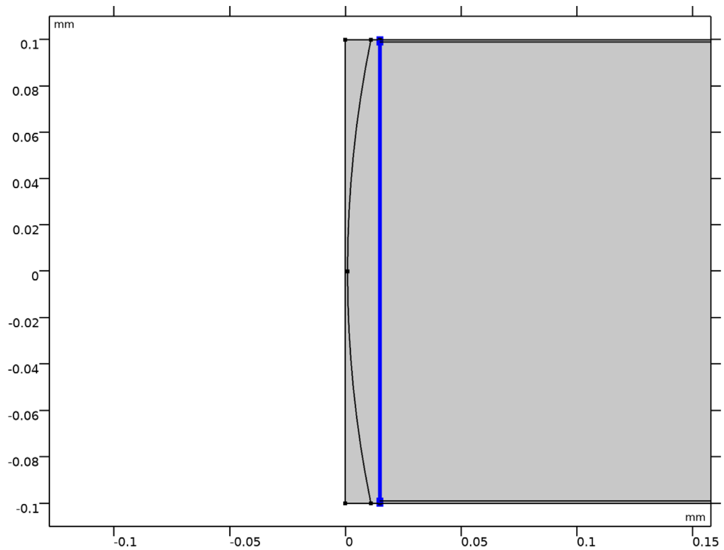
Near Field

1 In the **Definitions** toolbar, click **Explicit**.

2 In the **Settings** window for **Explicit**, type `Near Field` in the **Label** text field.

3 Locate the **Input Entities** section. From the **Geometric entity level** list, choose **Boundary**.

4 Select Boundaries 6, 8, and 10 only.



Boundaries Adjacent to Air

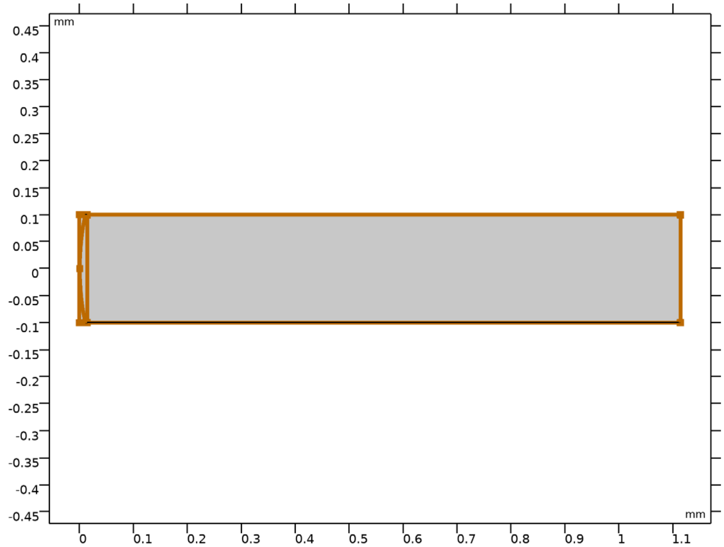
1 In the **Definitions** toolbar, click **Adjacent**.

2 In the **Settings** window for **Adjacent**, type `Boundaries Adjacent to Air` in the **Label** text field.

3 Locate the **Input Entities** section. Under **Input selections**, click **Add**.

4 In the **Add** dialog box, select **Air** in the **Input selections** list.

5 Click **OK**.



Boundaries Adjacent to the Lens

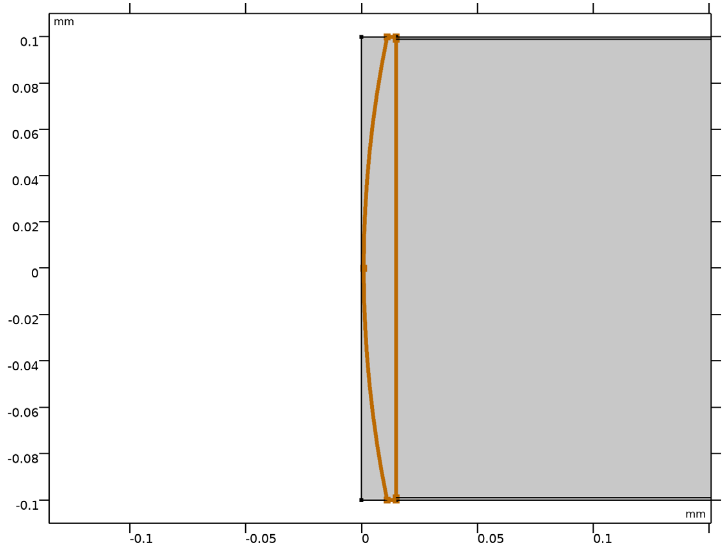
1 In the **Definitions** toolbar, click **Adjacent**.

2 In the **Settings** window for **Adjacent**, type `Boundaries Adjacent to the Lens` in the **Label** text field.

3 Locate the **Input Entities** section. Under **Input selections**, click **Add**.

4 In the **Add** dialog box, select **Lens** in the **Input selections** list.

5 Click **OK**.



Boundaries Adjacent to Both Air and the Lens

1 In the **Definitions** toolbar, click **Intersection**.

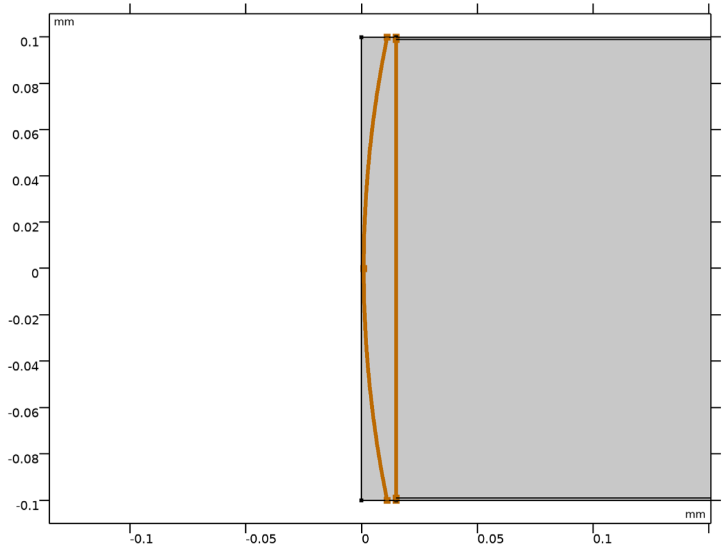
2 In the **Settings** window for **Intersection**, type `Boundaries Adjacent to Both Air and the Lens` in the **Label** text field.

3 Locate the **Geometric Entity Level** section. From the **Level** list, choose **Boundary**.

4 Locate the **Input Entities** section. Under **Selections to intersect**, click **Add**.

5 In the **Add** dialog box, in the **Selections to intersect** list, choose **Boundaries Adjacent to Air** and **Boundaries Adjacent to the Lens**.

6 Click **OK**.

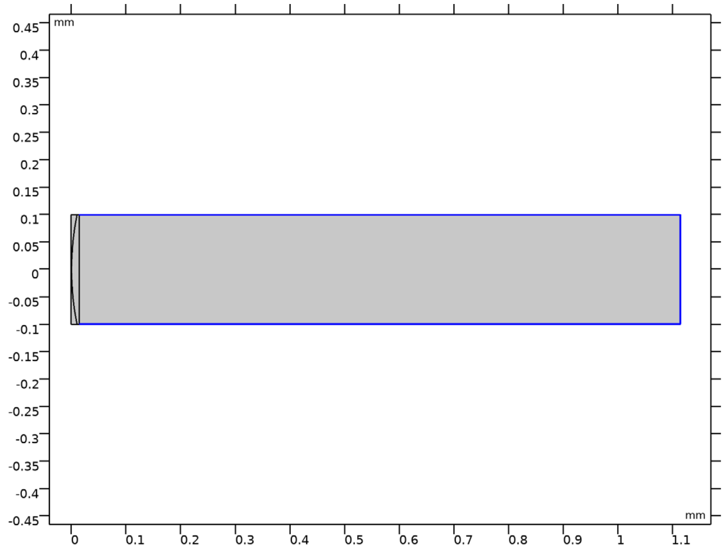


PMLs

1 In the **Definitions** toolbar, click **Explicit**.

2 In the **Settings** window for **Explicit**, type `PMLs` in the **Label** text field.

3 Select Domains 3 and 5–8 only, by first including domains 3-8 using the **Select Box** and then removing domain 4 from the entity list.



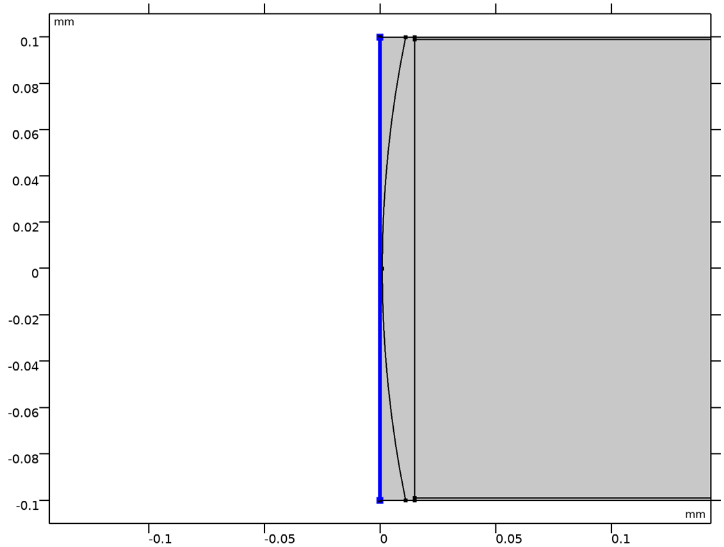
Input Boundary

1 In the **Definitions** toolbar, click **Explicit**.

2 In the **Settings** window for **Explicit**, type `Input Boundary` in the **Label** text field.

3 Locate the **Input Entities** section. From the **Geometric entity level** list, choose **Boundary**.

4 Select Boundary 1 only.



Now, add a variable representing the refractive index.

Variables 1

1 In the **Model Builder** window, right-click **Definitions** and choose **Variables**.

2 In the **Settings** window for **Variables**, locate the **Variables** section.

3 In the table, enter the following settings:

Name	Expression	Unit	Description
n	1		Air

4 Locate the **Geometric Entity Selection** section. From the **Geometric entity level** list, choose **Domain**.

5 From the **Selection** list, choose **Air**.

Variables 2

1 Right-click **Definitions** and choose **Variables**.

2 In the **Settings** window for **Variables**, locate the **Variables** section.

3 In the table, enter the following settings:

Name	Expression	Unit	Description
n	n_lens		Lens

4 Locate the **Geometric Entity Selection** section. From the **Geometric entity level** list, choose **Domain**.

5 From the **Selection** list, choose **Lens**.

To propagate the boundary field using the Fresnel diffraction formula in the first study, the integration operator is defined on the near-field boundary.

Integration 1 (intop1)

1 In the **Definitions** toolbar, click **Nonlocal Couplings** and choose **Integration**.

2 In the **Settings** window for **Integration**, locate the **Source Selection** section.

3 From the **Geometric entity level** list, choose **Boundary**.

4 From the **Selection** list, choose **Near Field**.

MATERIALS

Add materials for the lens and the surrounding air. The material for the AR coating will be added after the Transition boundary condition has been added to the physics.

Air

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Materials** and choose **Blank Material**.

2 In the **Settings** window for **Material**, type `Air` in the **Label** text field.

3 Locate the **Geometric Entity Selection** section. From the **Selection** list, choose **Air**.

4 Locate the **Material Contents** section. In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Refractive index, real part	n_iso ; nii = n_iso, nij = 0	1	1	Refractive index
Refractive index, imaginary part	ki_iso ; kiii = ki_iso, kiij = 0	0	1	Refractive index

Glass

1 Right-click **Materials** and choose **Blank Material**.

2 In the **Settings** window for **Material**, type `Glass` in the **Label** text field.

3 Locate the **Geometric Entity Selection** section. From the **Selection** list, choose **Lens**.

4 Locate the **Material Contents** section. In the table, enter the following settings:

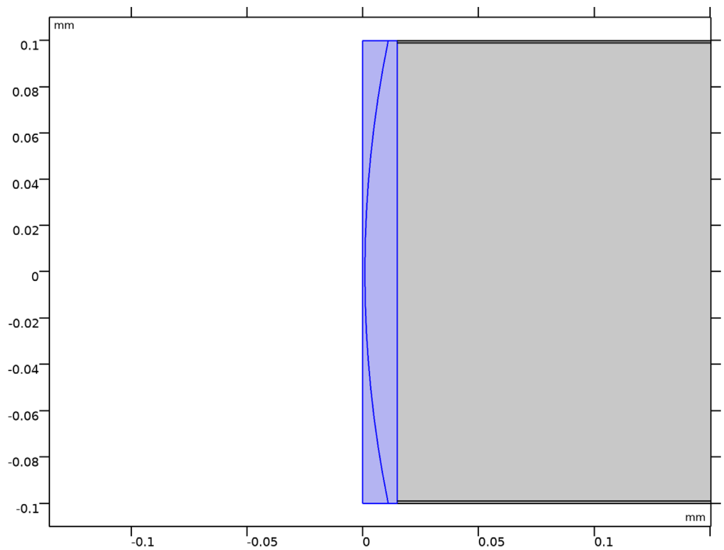
Property	Variable	Value	Unit	Property group
Refractive index, real part	n_iso ; nii = n_iso, nij = 0	n_lens	1	Refractive index
Refractive index, imaginary part	ki_iso ; kiii = ki_iso, kiij = 0	0	1	Refractive index

ELECTROMAGNETIC WAVES, FREQUENCY DOMAIN (EWFD)

In the first study, the Electromagnetic Waves, Frequency Domain interface computes only the near-field.

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Electromagnetic Waves, Frequency Domain (ewfd)**.

2 Select Domains 1 and 2 only, by selecting entities 3-8 in the entity list in the **Domain Selection** section and clicking the **Remove from Selection** button.



3 In the **Settings** window for **Electromagnetic Waves, Frequency Domain**, locate the **Components** section.

4 From the **Electric field components solved for** list, choose **Out-of-plane vector**.

Scattering Boundary Condition 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Scattering Boundary Condition**.

2 In the **Settings** window for **Scattering Boundary Condition**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **Input Boundary**.

4 Locate the **Scattering Boundary Condition** section. From the **Incident field** list, choose **Wave given by E field**.

5 Specify the $\mathbf{E}_0$ vector as

`0`	x
`0`	y
`1[V/m]*(abs(y)<w)`	z

This defines an incident wave polarized in the z direction with a constant amplitude of, `1[V/m]`, inside the beam width `2*w`.

Scattering Boundary Condition 2

1 In the **Physics** toolbar, click **Boundaries** and choose **Scattering Boundary Condition**.

2 In the **Settings** window for **Scattering Boundary Condition**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **Near Field**.

Transition Boundary Condition 1

Now, add a Transition boundary condition that represents the AR coating on the lens.

1 In the **Physics** toolbar, click **Boundaries** and choose **Transition Boundary Condition**.

2 In the **Settings** window for **Transition Boundary Condition**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **Boundaries Adjacent to the Lens**.

4 Locate the **Transition Boundary Condition** section. In the d text field, type `d_AR`.

MATERIALS

Add the material for the AR coating.

AR Coating

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Materials** and choose **Blank Material**.

2 In the **Settings** window for **Material**, type `AR Coating` in the **Label** text field.

3 Locate the **Geometric Entity Selection** section. From the **Geometric entity level** list, choose **Boundary**.

4 From the **Selection** list, choose **Boundaries Adjacent to the Lens**.

5 Locate the **Material Contents** section. In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Refractive index, real part	n_iso ; nii = n_iso, nij = 0	n_AR	1	Refractive index
Refractive index, imaginary part	ki_iso ; kiii = ki_iso, kiij = 0	0	1	Refractive index

STUDY 1

Step 1: Wavelength Domain

1 In the **Model Builder** window, under **Study 1** click **Step 1: Wavelength Domain**.

2 In the **Settings** window for **Wavelength Domain**, locate the **Study Settings** section.

3 In the **Wavelengths** text field, type `wl`.

4 In the **Home** toolbar, click **= Compute**.

DEFINITIONS

To make a better plot, create a new view with a different aspect ratio.

View 2

In the **Model Builder** window, under **Component 1 (comp1)** right-click **Definitions** and choose **View**.

Axis

1 In the **Model Builder** window, expand the **View 2** node, then click **Axis**.

2 In the **Settings** window for **Axis**, locate the **Axis** section.

3 From the **View scale** list, choose **Manual**.

4 In the **x scale** text field, type `2`.

RESULTS

Electric Field (ewfd)

1 In the **Model Builder** window, under **Results** click **Electric Field (ewfd)**.

2 In the **Settings** window for **2D Plot Group**, locate the **Plot Settings** section.

3 From the **View** list, choose **View 2**.

Surface 1

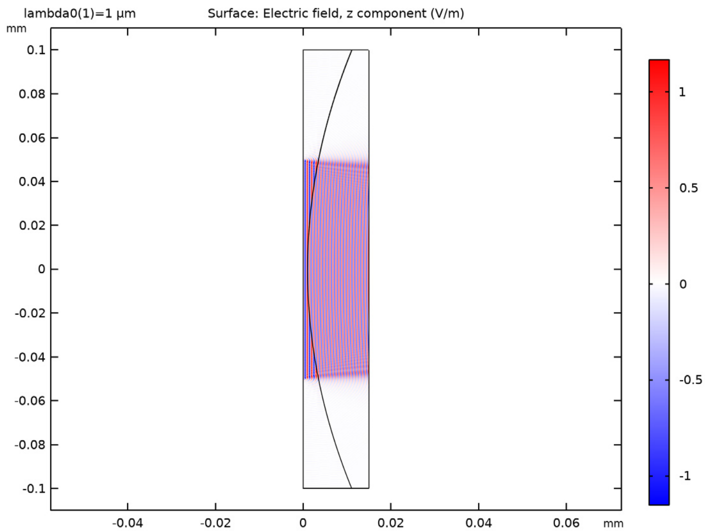
1 In the **Model Builder** window, expand the **Electric Field (ewfd)** node, then click **Surface 1**.

2 In the **Settings** window for **Surface**, locate the **Expression** section.

3 In the **Expression** text field, type `ewfd.Ez`.

4 Locate the **Coloring and Style** section. From the **Color table** list, choose **WaveLight**.

5 Click the **Zoom Extents** button in the **Graphics** toolbar.



This plot should look similar to the left plot in Figure 2.

Near Field

Now, create a plot of the near-field.

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Near Field` in the **Label** text field.

Line Graph 1

1 Right-click **Near Field** and choose **Line Graph**.

2 In the **Settings** window for **Line Graph**, locate the **Selection** section.

3 From the **Selection** list, choose **Near Field**.

4 Locate the **y-Axis Data** section. In the **Expression** text field, type `ewfd.Ez`.

5 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

6 In the **Expression** text field, type `y`.

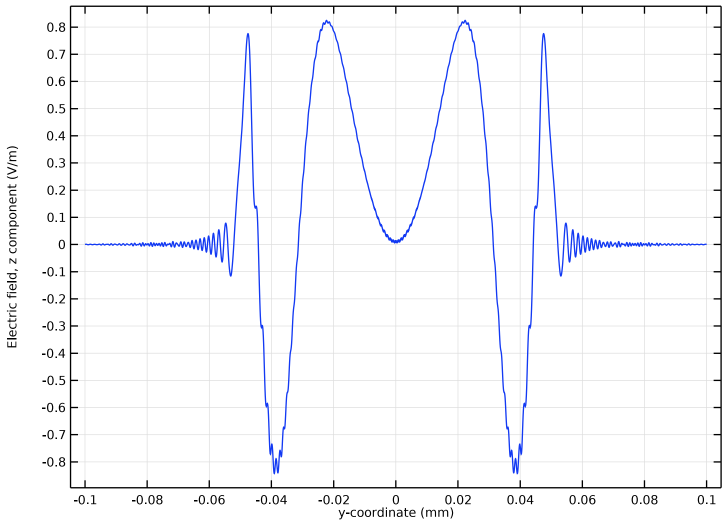
7 In the **Near Field** toolbar, click **Plot**.

Near Field

1 In the **Model Builder** window, click **Near Field**.

2 In the **Settings** window for **1D Plot Group**, click to expand the **Title** section.

3 From the **Title type** list, choose **None**.



Grid 1D 1

To plot the transformed electric field at the focal plane, create a dataset for a new spatial variable u in the focal plane.

1 In the **Results** toolbar, click **More Datasets** and choose **Grid>Grid 1D**.

2 In the **Settings** window for **Grid 1D**, locate the **Parameter Bounds** section.

3 In the **Name** text field, type `u`.

4 In the **Minimum** text field, type `-H/2`.

5 In the **Maximum** text field, type `H/2`.

Focal Plane

1 In the **Results** toolbar, click **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Focal Plane` in the **Label** text field.

3 Locate the **Title** section. From the **Title type** list, choose **None**.

4 Locate the **Plot Settings** section. Select the **y-axis label** check box.

5 In the associated text field, type `Electric field norm (V/m)`.

Line Graph 1

1 Right-click **Focal Plane** and choose **Line Graph**.

2 In the **Settings** window for **Line Graph**, locate the **Data** section.

3 From the **Dataset** list, choose **Grid 1D 1**.

Type the expression for the Fresnel diffraction formula.

4 Locate the **y-Axis Data** section. In the **Expression** text field, type `3/2.5*sqrt(1/wl/f*intop1(ewfd.Ez*exp(-i*k*y^2/(2*f))*exp(i*2*pi*dest(u)*y/(wl*f)))*conj(intop1(ewfd.Ez*exp(-i*k*y^2/(2*f))*exp(i*2*pi*dest(u)*y/(wl*f)))))`.

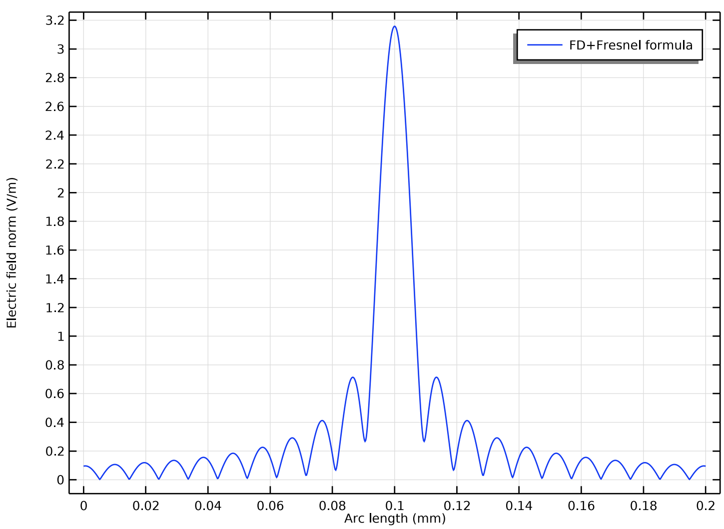
5 Click to expand the **Legends** section. Select the **Show legends** check box.

6 From the **Legends** list, choose **Manual**.

7 In the table, enter the following settings:

Legends
`FD+Fresnel formula`

8 In the **Focal Plane** toolbar, click **Plot**.



ADD PHYSICS

In the second part of this model, the Electromagnetic Waves, Beam Envelopes interface analyzes the entire domain.

1 In the **Home** toolbar, click **Add Physics** to open the **Add Physics** window.
2 Go to the **Add Physics** window.
3 In the tree, select **Optics>Wave Optics>Electromagnetic Waves, Beam Envelopes (ewbe)**.
4 Click **Add to Component 1** in the window toolbar.
5 In the **Home** toolbar, click **Add Physics** to close the **Add Physics** window.

DEFINITIONS

Perfectly Matched Layer 1 (pml1)

1 In the **Definitions** toolbar, click **Perfectly Matched Layer**.
2 In the **Settings** window for **Perfectly Matched Layer**, locate the **Domain Selection** section.
3 From the **Selection** list, choose **PMLs**.

ELECTROMAGNETIC WAVES, BEAM ENVELOPES (EWBE)

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Electromagnetic Waves, Beam Envelopes (ewbe)**.
2 In the **Settings** window for **Electromagnetic Waves, Beam Envelopes**, locate the **Components** section.
3 From the **Electric field components solved for** list, choose **Out-of-plane vector**.
4 Locate the **Wave Vectors** section. From the **Number of directions** list, choose **Unidirectional**.
5 Specify the $\mathbf{k}_1$ vector as

k*n	x
0	y

Matched Boundary Condition 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Matched Boundary Condition**.
2 In the **Settings** window for **Matched Boundary Condition**, locate the **Boundary Selection** section.
3 From the **Selection** list, choose **Input Boundary**.
4 Locate the **Matched Boundary Condition** section. From the **Incident field** list, choose **Electric field**.

5 Specify the $\mathbf{E}_0$ vector as

0	x
0	y
1[V/m]*(abs(y)<w)	z

Transition Boundary Condition 1

Also for this physics interface, add a Transition boundary condition to represent the AR coating on the lens surface.

1 In the **Physics** toolbar, click **Boundaries** and choose **Transition Boundary Condition**.

2 In the **Settings** window for **Transition Boundary Condition**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **Boundaries Adjacent to the Lens**.

4 Locate the **Propagation Direction** section. From the list, choose **From wave vector**.

This setting assumes that the wave is incident on the Transition boundary condition boundaries with the wave vector as specified in the **Wave Vectors** section in the settings for the physics interface. This is a slightly better assumption than assuming that the wave propagates in the normal direction to the Transition boundary condition boundaries, which is what the other option represents.

5 Locate the **Transition Boundary Condition** section. In the d text field, type `d_AR`.

DEFINITIONS

Perfectly Matched Layer 1 (pml1)

1 In the **Model Builder** window, under **Component 1 (comp1)>Definitions>Artificial Domains** click **Perfectly Matched Layer 1 (pml1)**.

2 In the **Settings** window for **Perfectly Matched Layer**, locate the **Scaling** section.

3 From the **Physics** list, choose **Electromagnetic Waves, Beam Envelopes (ewbe)**.

MESH 1

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Mesh 1**.

2 In the **Settings** window for **Mesh**, locate the **Physics-Controlled Mesh** section.

3 In the table, clear the **Use** check box for **Electromagnetic Waves, Beam Envelopes (ewbe)**.

This makes sure that the first mesh is controlled only by the Electromagnetic Waves, Frequency Domain interface.

COMPONENT 1 (COMP1)

Now, add a mesh used by the Electromagnetic Waves, Beam Envelopes interface.

MESH 2

In the **Mesh** toolbar, click **Add Mesh**.

Mapped 1

1 In the **Mesh** toolbar, click **Mapped**.

2 In the **Settings** window for **Mapped**, locate the **Domain Selection** section.

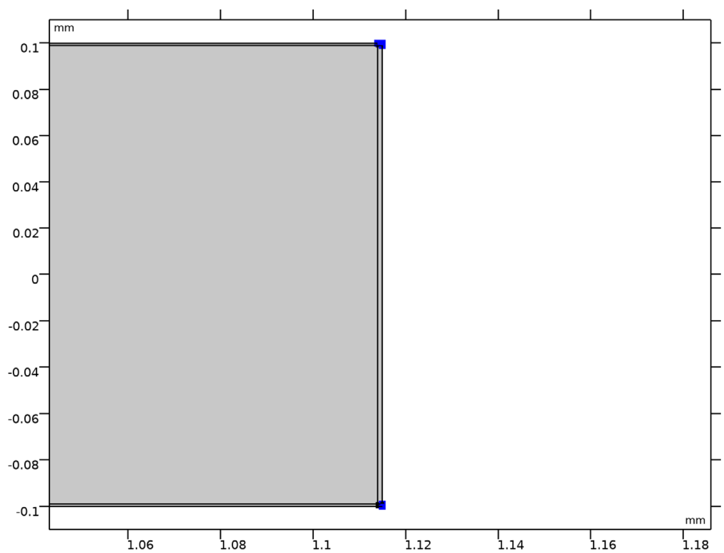
3 From the **Geometric entity level** list, choose **Domain**.

4 From the **Selection** list, choose **PMLs**.

Distribution 1

1 Right-click **Mapped 1** and choose **Distribution**.

2 Select Boundaries 19, 20, and 22 only.



3 In the **Settings** window for **Distribution**, locate the **Distribution** section.

4 In the **Number of elements** text field, type 10.

Size

1 In the **Model Builder** window, click **Size**.

2 In the **Settings** window for **Size**, locate the **Element Size** section.

3 Click the **Custom** button.

4 Locate the **Element Size Parameters** section. In the **Maximum element size** text field, type `wl`.

Free Triangular 1

In the **Mesh** toolbar, click **Free Triangular**.

ADD STUDY

1 In the **Home** toolbar, click **Add Study** to open the **Add Study** window.

2 Go to the **Add Study** window.

3 Find the **Studies** subsection. In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces>Wavelength Domain**.

4 Find the **Physics interfaces in study** subsection. In the table, clear the **Solve** check box for **Electromagnetic Waves, Frequency Domain (ewfd)**.

5 Click **Add Study** in the window toolbar.

6 In the **Home** toolbar, click **Add Study** to close the **Add Study** window.

STUDY 2

Step 1: Wavelength Domain

1 In the **Settings** window for **Wavelength Domain**, locate the **Study Settings** section.

2 In the **Wavelengths** text field, type `wl`.

3 In the **Home** toolbar, click **Compute**.

DEFINITIONS

View 3

In the **Model Builder** window, under **Component 1 (comp1)** right-click **Definitions** and choose **View**.

Axis

1 In the **Model Builder** window, expand the **View 3** node, then click **Axis**.

2 In the **Settings** window for **Axis**, locate the **Axis** section.

3 From the **View scale** list, choose **Manual**.

4 In the **y scale** text field, type `2`.

RESULTS

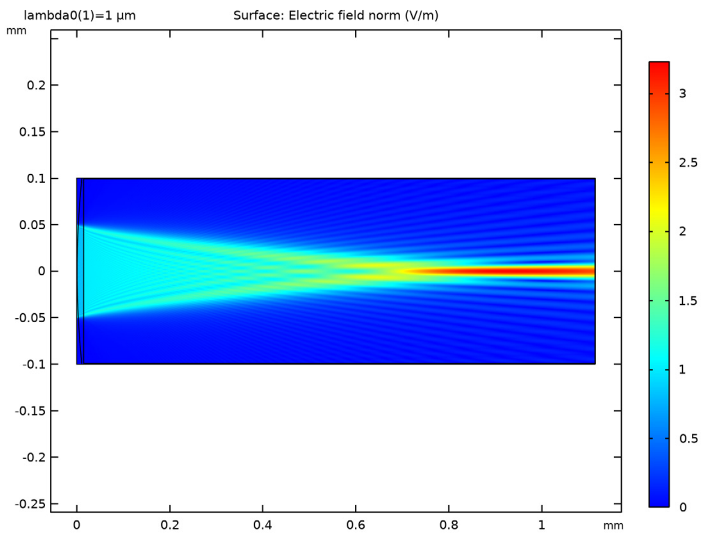
Electric Field (ewbe)

1 In the **Model Builder** window, under **Results** click **Electric Field (ewbe)**.

2 In the **Settings** window for **2D Plot Group**, locate the **Plot Settings** section.

3 From the **View** list, choose **View 3**.

4 Click the **Zoom Extents** button in the **Graphics** toolbar.



Cut Line 2D 1

Now create a plot comparing the results in the focal plane from the Fresnel diffraction formula of the near field from the Electromagnetic Waves, Frequency Domain solution and the Electromagnetic Waves, Beam Envelopes simulation for the whole domain.

1 In the **Results** toolbar, click **Cut Line 2D**.

2 In the **Settings** window for **Cut Line 2D**, locate the **Data** section.

3 From the **Dataset** list, choose **Study 2/Solution 2 (sol2)**.

4 Locate the **Line Data** section. In row **Point 1**, set **X** to `f`.

5 In row **Point 1**, set **Y** to `-H`.

6 In row **Point 2**, set **X** to `f`.

7 In row **Point 2**, set **Y** to `H`.

Line Graph 2

1 In the **Model Builder** window, right-click **Focal Plane** and choose **Line Graph**.

2 In the **Settings** window for **Line Graph**, locate the **Data** section.

3 From the **Dataset** list, choose **Cut Line 2D 1**.

4 Locate the **y-Axis Data** section. In the **Expression** text field, type `ewbe.normE`.

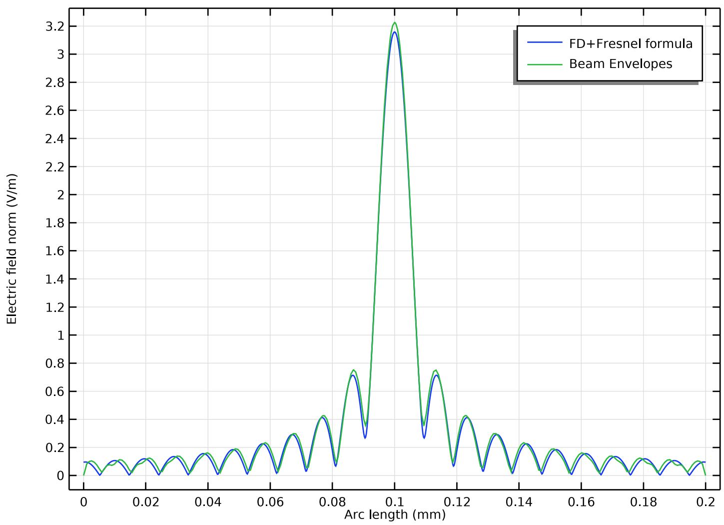
5 Locate the **Legends** section. Select the **Show legends** check box.

6 From the **Legends** list, choose **Manual**.

7 In the table, enter the following settings:

Legends
`Beam Envelopes`

8 In the **Focal Plane** toolbar, click **Plot**.



Finally, create a plot of the field distribution along the optical axis.

Cut Line 2D 2

1 In the **Results** toolbar, click **Cut Line 2D**.

2 In the **Settings** window for **Cut Line 2D**, locate the **Data** section.

3 From the **Dataset** list, choose **Study 2/Solution 2 (sol2)**.

4 Locate the **Line Data** section. In row **Point 2**, set **X** to `W_lens+W_air`.

Propagation Direction

1 In the **Results** toolbar, click **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Propagation Direction` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Cut Line 2D 2**.

4 Locate the **Plot Settings** section. Select the **x-axis label** check box.

5 In the associated text field, type `Propagation length (mm)`.

Line Graph 1

1 Right-click **Propagation Direction** and choose **Line Graph**.

2 In the **Settings** window for **Line Graph**, locate the **y-Axis Data** section.

3 In the **Expression** text field, type `ewbe.normE`.

4 In the **Propagation Direction** toolbar, click **Plot**.