Hexagonal Grating

Introduction

A hexagonal grating is an infinite structure that is periodic with hexagonal (or rhomboid unit) cells. Figure 1 shows the hexagonal domain used for this model. The reflecting perfectly conducting surface consists of regularly spaced protruding semispheres.

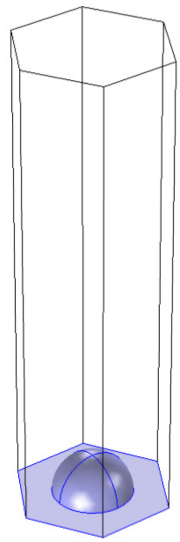


Figure 1: The hexagonal domain, used for computing the diffraction from the hexagonal grating.

As shown in Figure 2, for a hexagonal cell of side length a, the corresponding unit cell is a rhomboid with side length $\sqrt{3}a$. In Figure 2, the side vectors for the hexagonal cell starts from the point P and are denoted $\mathbf{a}_1$ and $\mathbf{a}_2$. The angle between $\mathbf{a}_1$ and $\mathbf{a}_2$ is 120 degrees. Similarly, for the rhomboid unit cell, the primitive vectors are denoted $\mathbf{u}_1$

and $\mathbf{u}_2$ and starts from the hexagon center point Q. The angle between the two primitive vectors is also 120 degrees.

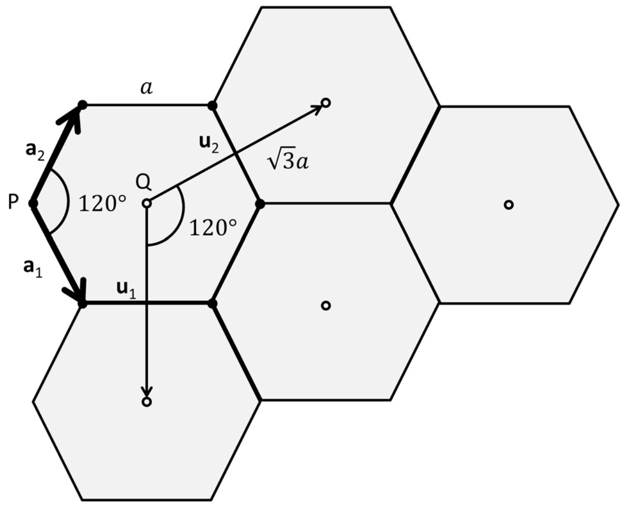


Figure 2: Schematic showing the hexagonal cells with side length a *and side vectors* $\mathbf{a}_1$ *and* $\mathbf{a}_2$*. The primitive cells are defined by the primitive vectors* $\mathbf{u}_1$ *and* $\mathbf{u}_2$*.*

If the incident plane wave have a wave vector defined by

$$\mathbf{k} = \mathbf{k}_{||} + \mathbf{k}_{\perp}, \qquad (1)$$

where $\mathbf{k}_{||}$ is the wave vector component parallel to the periodic boundary and $\mathbf{k}\perp$ is the component orthogonal to the periodic boundary, the in-plane wave vector component for diffraction order mn is given by

$$\mathbf{k}_{||mn} = \mathbf{k}_{||} + m\mathbf{G}_1 + n\mathbf{G}_2, \qquad (2)$$

where the reciprocal lattice vectors $\mathbf{G}_1$ and $\mathbf{G}_2$ are defined from the primitive vectors $\mathbf{u}_1$ and $\mathbf{u}_2$ as

$$\mathbf{G}_1 = 2\pi\frac{\mathbf{u}_2 \times \mathbf{n}}{\mathbf{u}_1 \cdot (\mathbf{u}_2 \times \mathbf{n})} \qquad (3)$$

and

$$\mathbf{G}_2 = 2\pi\frac{\mathbf{n}\times\mathbf{u}_1}{\mathbf{u}_2\cdot(\mathbf{n}\times\mathbf{u}_1)}, \tag{4}$$

where $\mathbf{n}$ is the normal vector (length 1) to the periodic boundary.

Since the out-of-plane wave vector component for mode mn is defined by

$$k_{\perp mn} = \sqrt{k^2 - k_{||mn}^2}, \tag{5}$$

it is clear that for propagating modes, where the out-of-plane wave vector component above must be real, the length of the in-plane wave vector component must be smaller than the material wave number k. Figure 3 shows that it is only the modes inside the circle with radius k that will be propagating. In the example shown in Figure 3, there are five modes that will be propagating, in this case the modes $m = n = 0$ (the reflected wave), $m = -1$, $n = 0$, $m = 0$, $n = -1$, $m = -1$, $n = -1$, and $m = -2$, $n = -1$. All other modes will be evanescent and damped out.

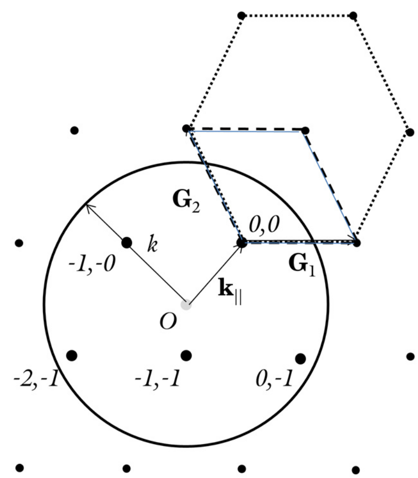


Figure 3: The reciprocal lattice, showing the reciprocal lattice vectors $\mathbf{G}_1$ *and* $\mathbf{G}_2$*, the in-plane wave vector component* $\mathbf{k}_{||}$*, and the circle with radius* k *(the material wave number) enclosing the propagating mode points (larger dots. The dotted hexagon indicates that also the reciprocal lattice is a hexagonal point lattice. The dashed rhomboid indicates the unit cell spanned by the reciprocal lattice vectors.*

Model Definition

In this model, the unit cell is small compared to the wavelength, so there will only be two modes that are propagating, the modes $m = 0$, $n = -1$ and $m = -1$, $n = -1$. For wavelengths longer than approximately 1.01 μm (the critical wavelength), the mode $m = 0$, $n = -1$ will be evanescent.

First a wavelength sweep will be made for an incident field having the polarization perpendicular to the plane of incidence (spanned by the wave vector for the incident wave and the normal to the periodic boundary) (so called s-polarization). Thereafter another wavelength sweep is made, but now with the polarization in the plane of incidence (p-polarization).

Results and Discussion

Figure 4 shows the electric field norm and the propagation directions for the incident, the reflected and the diffracted waves. Notice that the diffracted waves come in pairs (both have the same mode numbers), one wave having the polarization in the plane-of-diffraction and the other wave have orthogonal polarization to the plane-of-diffraction. The plane-of-diffraction is spanned by the wave vector for the diffracted wave and the normal to the periodic boundary. The wavelength is close the critical wavelength for the

m = 0, n = -1 mode. This is evident from the plot, as the wave vector for that mode (the yellow arrows) is almost parallel to the periodic boundary.

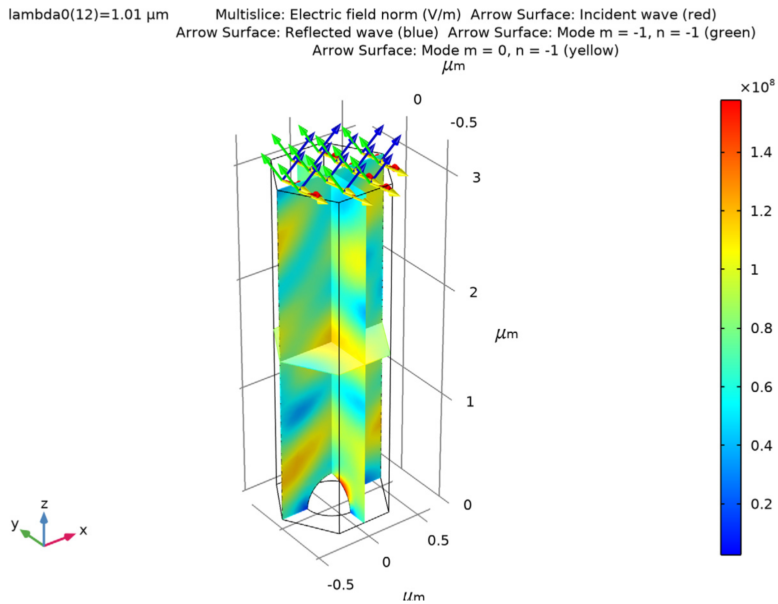


Figure 4: The electric field norm and the propagation directions for the incident wave (red arrows), the reflected wave (blue arrows) and the two diffraction orders (green and yellow arrows). The wavelength is 1.01 µ*m, which is close to the critical wavelength for the mode* m *= 0,* n *= -1, and the polarization of the incident wave is perpendicular to the plane of incidence.*

Figure 5 shows the reflectance (for mode $m = n = 0$) and the diffraction efficiencies for the diffracted waves. Notice that both the reflectance and the diffraction efficiency for the in-plane-polarized m = -1, n = -1 mode show resonances (peaks or dips) close to the critical wavelength for the m = 0, n = -1 modes.

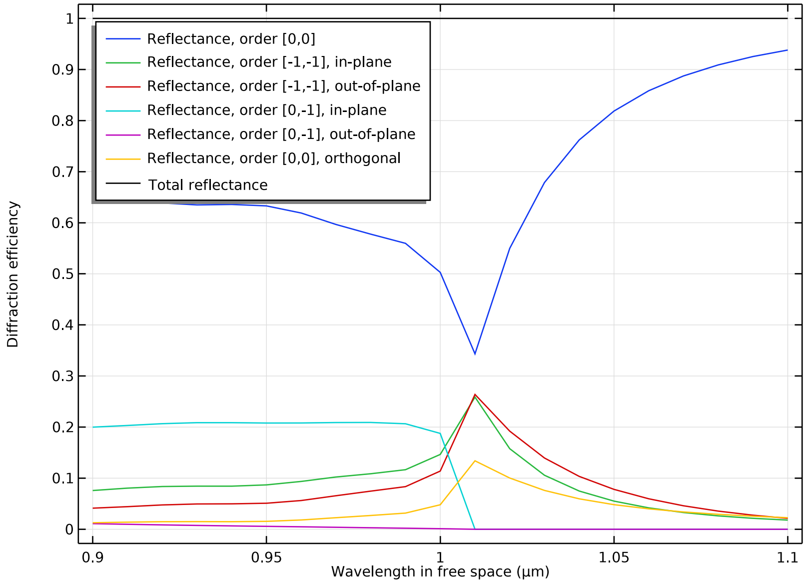


Figure 5: Diffraction efficiencies for the reflected wave and the diffracted waves. The polarization of the incident wave is perpendicular to the plane of incidence.

Figure 6 and Figure 7 show polarization plots for the same case as Figure 4 and Figure 5. It is clear that even though the polarization for the incident wave is linear, the polarization for the reflected diffraction orders are elliptical.

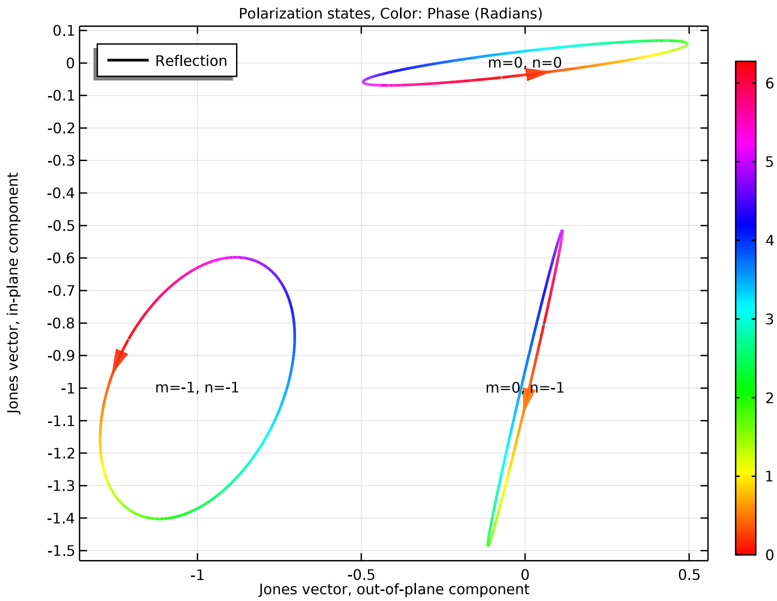


Figure 6: Polarization plot showing the polarization ellipses for the three diffraction orders that are not evanescent at the first wavelength, 0.9 μm.

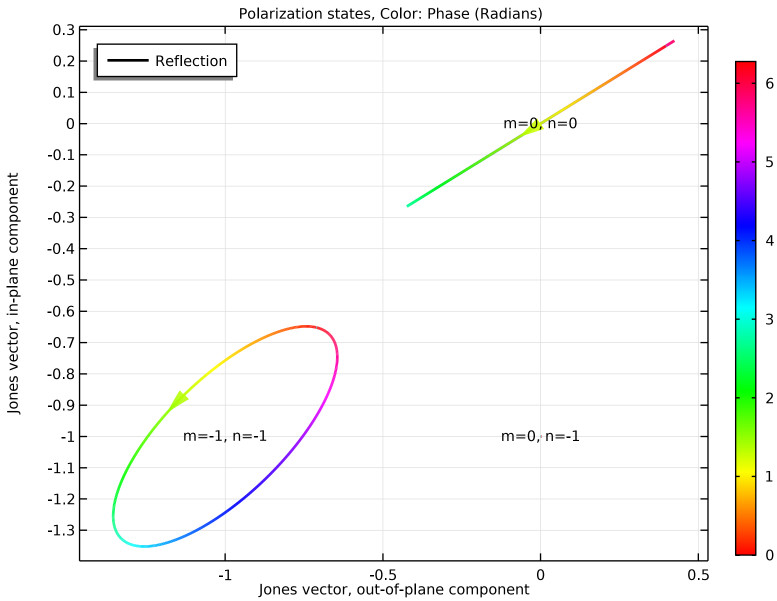


Figure 7: Polarization plot for the same case as Figure 6*, but at a wavelength of 1.01 μm where only two diffraction orders are propagating.*

Figure 8 shows a similar plot as Figure 4, but here the polarization of the incident wave is parallel with the plane of incidence.

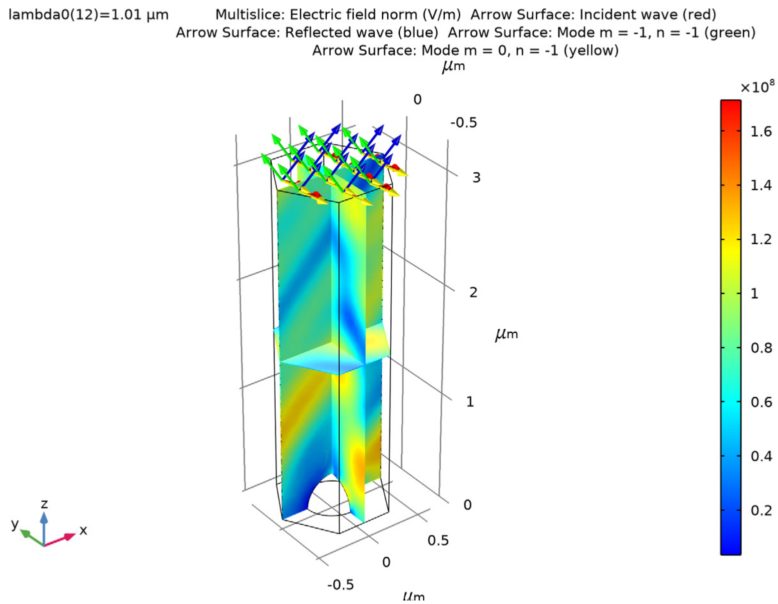


Figure 8: Similar plot as in Figure 4, but here the polarization of the incident wave is parallel to the plane of incidence.

Figure 9 shows that for p-polarization both the reflected wave and the two m = -1, n = -1 modes show resonances close to the critical wavelength for the m = 0, n = -1 mode.

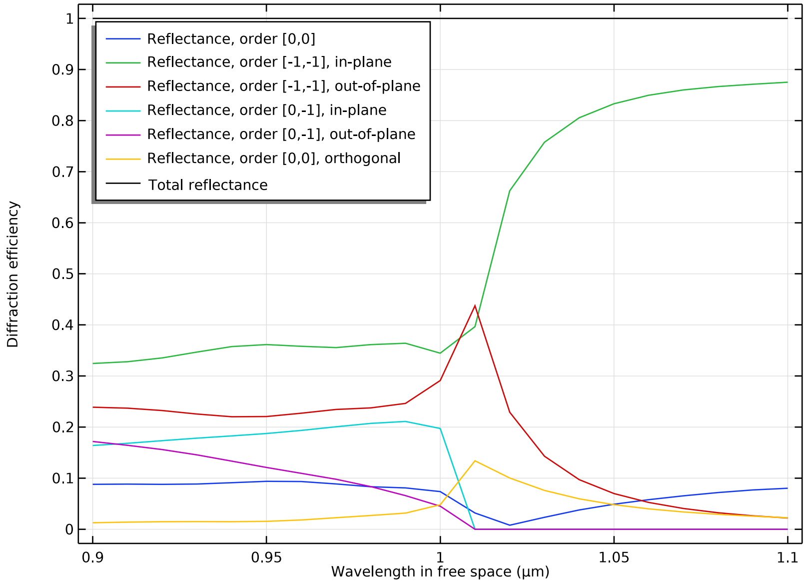


Figure 9: Similar plot as in Figure 5*, but here the polarization of the incident wave is parallel to the plane of incidence.*

Application Library path: `Wave_Optics_Module/Gratings_and_Metamaterials/hexagonal_grating`

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 **3D**.

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

First add some parameters that defines the geometry and the incident electric field.

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 In the table, enter the following settings:

Name	Expression	Value	Description
`lda0`	`1[um]`	1E-6 m	`Wavelength`
`a`	`lda0/2`	5E-7 m	`Hexagon side length`
`h0`	`3*lda0`	3E-6 m	`Air height`
`a1`	`a/2`	2.5E-7 m	`Sphere radius`
`theta`	`pi/3`	1.0472	`Elevation angle`
`phi`	`12[deg]`	0.20944 rad	`Azimuth angle`
`E0`	`1[V/m]`	1 V/m	`Electric field amplitude`
`H0`	`1[A/m]`	1 A/m	`Magnetic field amplitude`

Notice that the azimuth angle `phi` above measures the angle for the wave vector of the incident wave from the x-axis.

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 Click **Range**.

4 In the **Range** dialog box, type `0.9[um]` in the **Start** text field.

5 In the **Step** text field, type `0.01[um]`.

6 In the **Stop** text field, type `1.1[um]`.

7 Click **Replace**.

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 **µm**.

The geometry consists of an extruded hexagon, with a semisphere removed from it at the bottom.

Work Plane 1 (wp1)

1 In the **Geometry** toolbar, click **Work Plane**.

2 In the **Settings** window for **Work Plane**, click **Show Work Plane**.

Work Plane 1 (wp1)>Plane Geometry

In the **Model Builder** window, click **Plane Geometry**.

Work Plane 1 (wp1)>Polygon 1 (pol1)

1 In the **Work Plane** toolbar, click **Polygon**.

2 In the **Settings** window for **Polygon**, locate the **Coordinates** section.

3 In the table, enter the following settings:

xw (µm)	**yw (µm)**
a	0
a/2	sqrt(3)/2*a
-a/2	sqrt(3)/2*a
-a	0
-a/2	-sqrt(3)/2*a
a/2	-sqrt(3)/2*a

Extrude 1 (ext1)

1 In the **Model Builder** window, right-click **Geometry 1** and choose **Extrude**.

2 In the **Settings** window for **Extrude**, locate the **Distances** section.

3 In the table, enter the following settings:

Distances (µm)
h0

Sphere 1 (sph1)

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

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

3 In the **Radius** text field, type `a1`.

Difference 1 (dif1)

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

2 Select the object **ext1** only.

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

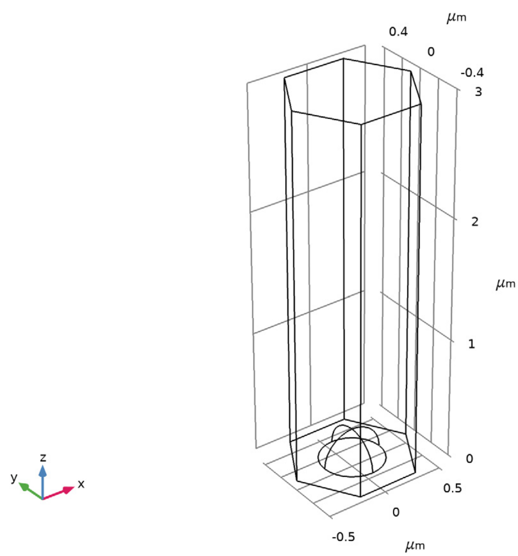
4 Find the **Objects to subtract** subsection. Select the **Activate Selection** toggle button.

5 Select the object **sph1** only.

6 Click **Build All Objects**.

7 Click the **Go to Default View** button in the **Graphics** toolbar.

8 Click the **Wireframe Rendering** button in the **Graphics** toolbar.



ADD MATERIAL

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

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

3 In the tree, select **Built-in>Air**.

4 Click **Add to Component** in the window toolbar.

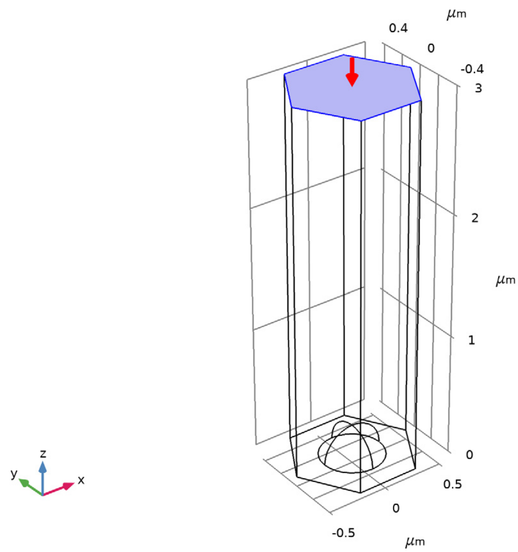
5 In the **Home** toolbar, click **Add Material** to close the **Add Material** window.

ELECTROMAGNETIC WAVES, FREQUENCY DOMAIN (EWFD)

Port 1

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

2 Select Boundary 4 only.



3 In the **Settings** window for **Port**, locate the **Port Properties** section.

4 From the **Type of port** list, choose **Periodic**.

For the first port, wave excitation is **on** by default.

5 Locate the **Port Mode Settings** section. Specify the $\mathbf{E}_0$ vector as

`-E0*sin(phi)`	x
`E0*cos(phi)`	y
`0`	z

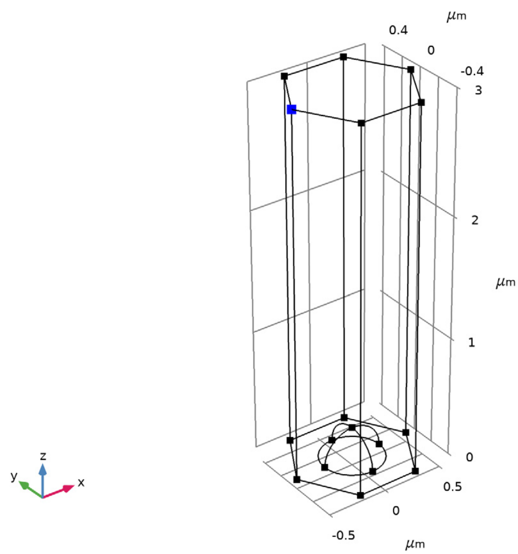
6 In the α_1 text field, type `theta`.

7 In the α_2 text field, type `phi+pi/3`, as this angle is measured from the first side vector of the port (not the x-axis).

Periodic Port Reference Point 1

Before creating the diffraction orders ports, a reference point must be defined on the periodic port.

1. In the **Physics** toolbar, click **Attributes** and choose **Periodic Port Reference Point**.
2. In the **Settings** window for **Periodic Port Reference Point**, locate the **Point Selection** section.
3. Click **Clear Selection**.
4. Select Point 2 only. This point selection makes the angle previously provided for `alpha_2` consistent with the intended angle of incidence for the incident wave.



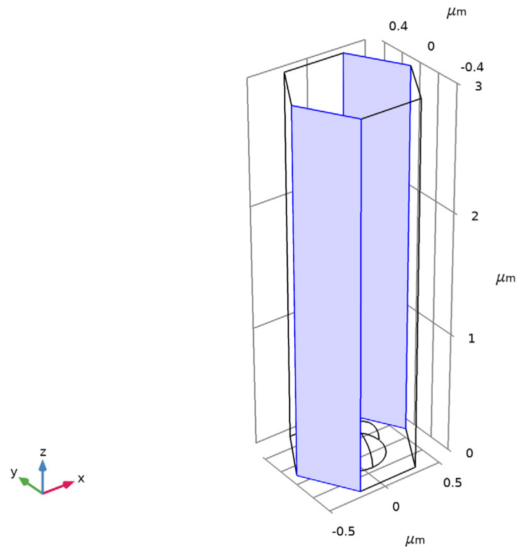
Port 1

1. In the **Model Builder** window, click **Port 1**.
2. In the **Settings** window for **Port**, locate the **Automatic Diffraction Order Calculation** section.
3. Click **Add Diffraction Orders**.

Periodic Condition 1

1. In the **Physics** toolbar, click **Boundaries** and choose **Periodic Condition**.
2. In the **Settings** window for **Periodic Condition**, locate the **Periodicity Settings** section.
3. From the **Type of periodicity** list, choose **Floquet periodicity**.
4. From the **k-vector for Floquet periodicity** list, choose **From periodic port**.

5 Select Boundaries 1 and 12 only.



Periodic Condition 2

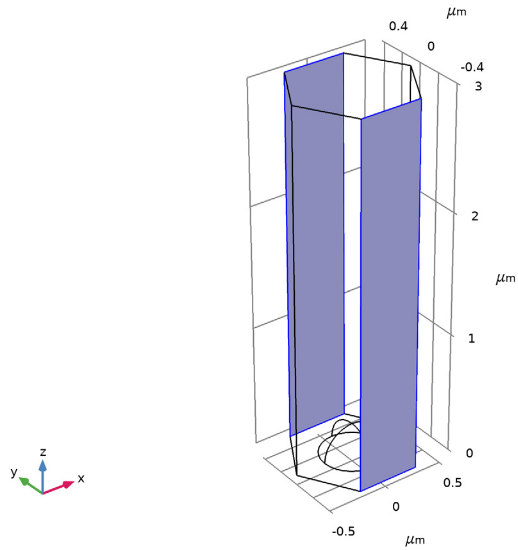
1 In the **Physics** toolbar, click **Boundaries** and choose **Periodic Condition**.

2 In the **Settings** window for **Periodic Condition**, locate the **Periodicity Settings** section.

3 From the **Type of periodicity** list, choose **Floquet periodicity**.

4 From the **k-vector for Floquet periodicity** list, choose **From periodic port**.

5 Select Boundaries 5 and 8 only.



Periodic Condition 3

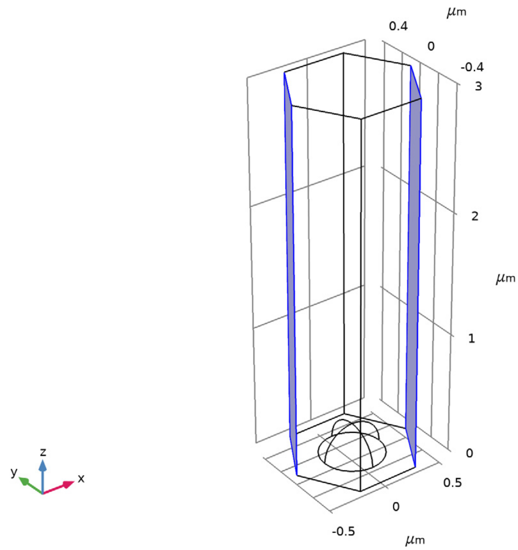
1 In the **Physics** toolbar, click **Boundaries** and choose **Periodic Condition**.

2 In the **Settings** window for **Periodic Condition**, locate the **Periodicity Settings** section.

3 From the **Type of periodicity** list, choose **Floquet periodicity**.

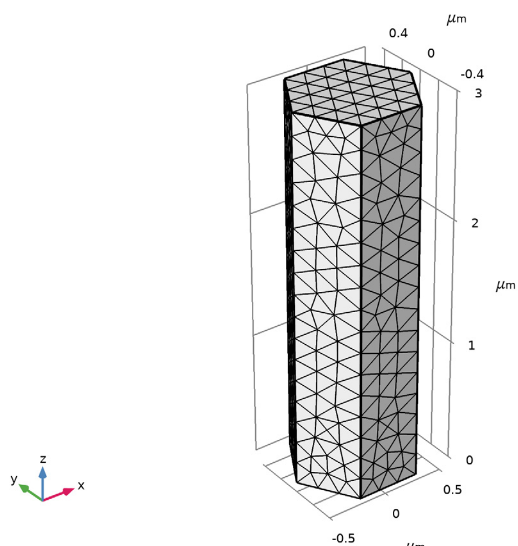
4 From the **k-vector for Floquet periodicity** list, choose **From periodic port**.

5 Select Boundaries 2 and 11 only.



MESH 1

In the **Model Builder** window, under **Component 1 (comp1)** right-click **Mesh 1** and choose **Build All**.



Study 1

Step 1: Wavelength Domain

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

Results

Electric Field (ewfd)

Add Arrow Surface plots showing the wave vector directions for the incident field, the reflected field and the diffracted fields. Notice that the diffracted fields come in pairs, where each pair have the same wave vector. Thus, only two wave vectors for the diffraction orders need to be added in this case.

Arrow Surface 1

1 Right-click **Electric Field (ewfd)** and choose **Arrow Surface**.
2 In the **Settings** window for **Arrow Surface**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)>Electromagnetic Waves, Frequency Domain>Ports>ewfd.kIncx_1,...,ewfd.kIncz_1 - Incident wave vector**.
3 Locate the **Expression** section. Select the **Description** check box.
4 In the associated text field, type `Incident wave (red)`.

Arrow Surface 2

1 Right-click **Arrow Surface 1** and choose **Duplicate**.
2 In the **Settings** window for **Arrow Surface**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)>Electromagnetic Waves, Frequency Domain>Ports>ewfd.kModex_1,...,ewfd.kModez_1 - Port mode wave vector**.
3 Locate the **Coloring and Style** section. From the **Color** list, choose **Blue**.
4 Locate the **Expression** section. In the **Description** text field, type `Reflected wave (blue)`.

Arrow Surface 3

1 Right-click **Arrow Surface 2** and choose **Duplicate**.
2 In the **Settings** window for **Arrow Surface**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)>Electromagnetic Waves, Frequency Domain>Ports>ewfd.kModex_2,...,ewfd.kModez_2 - Port mode wave vector**.
3 Locate the **Coloring and Style** section. From the **Color** list, choose **Green**.

4 Locate the **Expression** section. In the **Description** text field, type `Mode m = -1, n = -1 (green)`.

Arrow Surface 4

1 Right-click **Arrow Surface 3** and choose **Duplicate**.

2 In the **Settings** window for **Arrow Surface**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)>Electromagnetic Waves, Frequency Domain>Ports>ewfd.kModex_4,...,ewfd.kModez_4 - Port mode wave vector**.

3 Locate the **Coloring and Style** section. From the **Color** list, choose **Yellow**.

4 Locate the **Expression** section. In the **Description** text field, type `Mode m = 0, n = -1 (yellow)`.

Electric Field (ewfd)

Select the wavelength closest to the critical wavelength for the mode $m = 0$, $n = -1$.

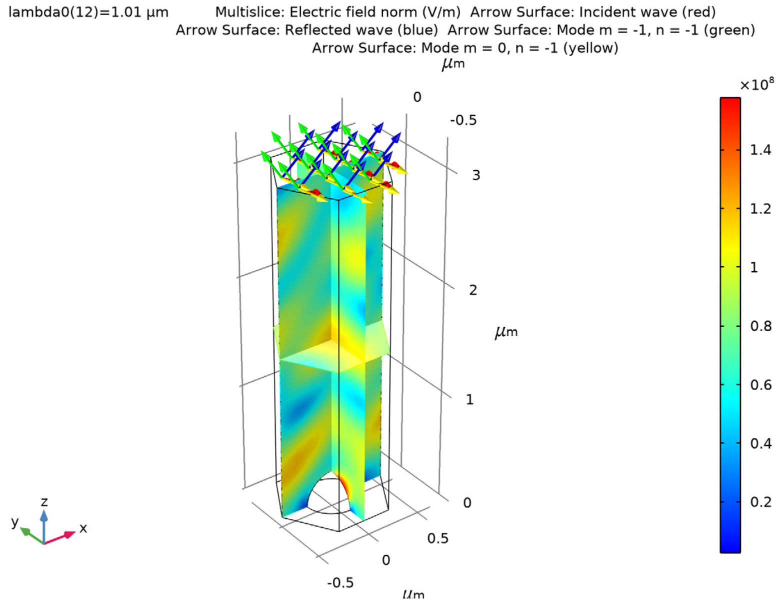
1 In the **Model Builder** window, click **Electric Field (ewfd)**.

2 In the **Settings** window for **3D Plot Group**, locate the **Data** section.

3 From the **Parameter value (lambda0 (µm))** list, choose **1.01**.

4 In the **Electric Field (ewfd)** toolbar, click **Plot**.

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



Your plot should look the same as Figure 4.

Reflectance (ewfd)

The reflectance and the diffraction efficiencies for the diffracted waves are plotted by default.

1 In the **Model Builder** window, click **Reflectance (ewfd)**.

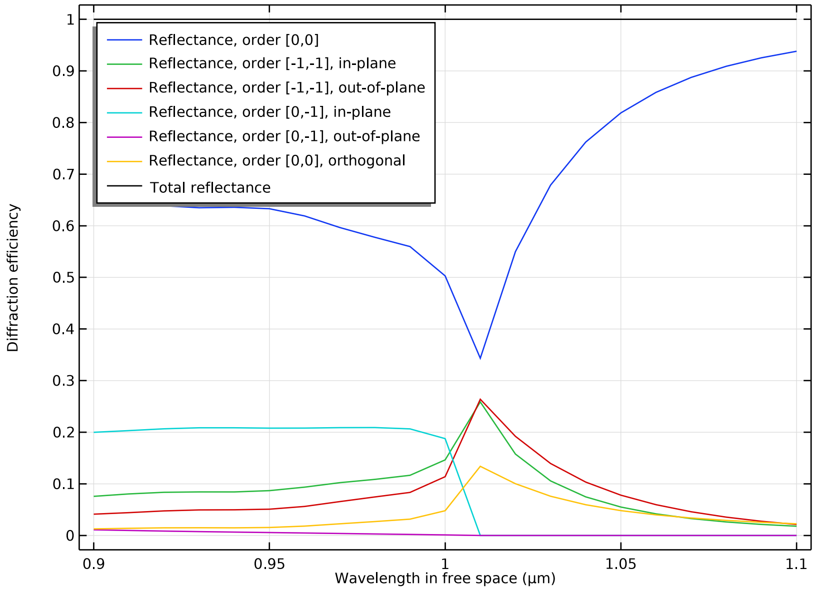
2 In the **Settings** window for **1D Plot Group**, click to expand the **Title** section.

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

4 Locate the **Plot Settings** section. In the **y-axis label** text field, type `Diffraction efficiency`.

5 Locate the **Legend** section. From the **Position** list, choose **Upper left**.

6 In the **Reflectance (ewfd)** toolbar, click **Plot**.



Your plot should look like Figure 5.

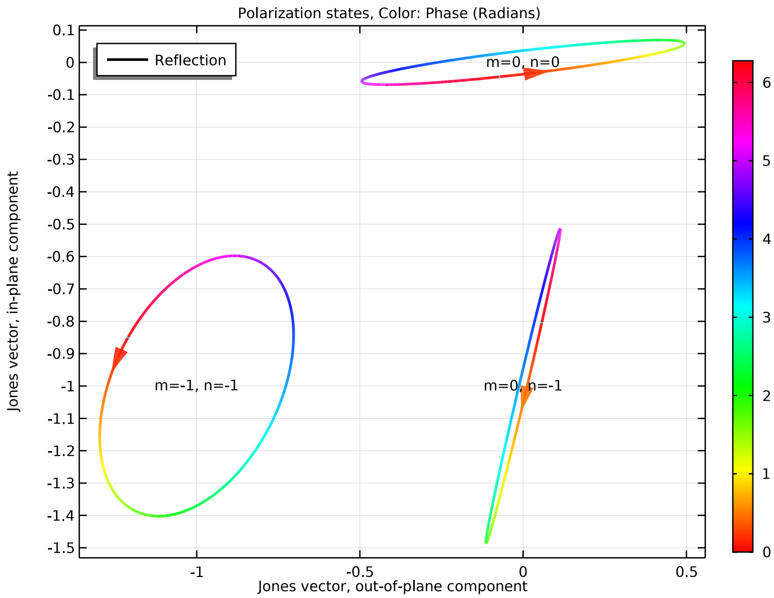
Polarization Plot (ewfd)

1 In the **Model Builder** window, click **Polarization Plot (ewfd)**.

2 In the **Settings** window for **1D Plot Group**, locate the **Legend** section.

3 From the **Position** list, choose **Upper left**.

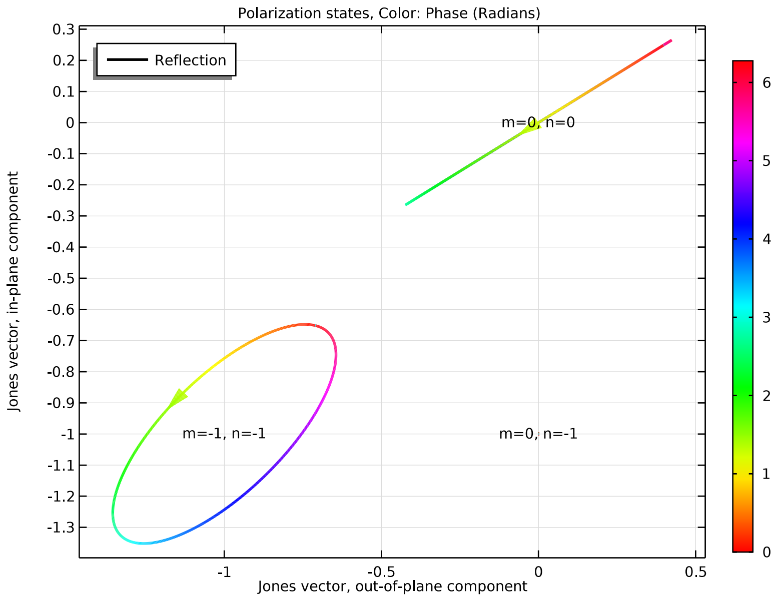
4 In the **Polarization Plot (ewfd)** toolbar, click **Plot**.



The polarization plot shows that all three modes are elliptically polarized, but with different orientations for the polarization ellipse.

5 Locate the **Data** section. In the **Parameter values (lambda0 (µm))** list, select **1.01**.

6 In the **Polarization Plot (ewfd)** toolbar, click **Plot**.



At this wavelength, mode m = 0, n = -1 is evanescent, so there is no polarization ellipse for that mode.

To really understand the polarization direction, you can also plot the Jones base vectors. First create a view zoomed in on the port boundary and then use the view in the created plot.

7 Click the **Show More Options** button in the **Model Builder** toolbar.

8 In the **Show More Options** dialog box, select **Results>Views** in the tree.

9 In the tree, select the check box for the node **Results>Views**.

10 Click **OK**.

View 3D 3

1 In the **Model Builder** window, right-click **Views** and choose **View 3D**.

2 Click the **Zoom Box** button in the **Graphics** toolbar and then use the mouse to zoom in on the port boundary.

Polarization Base Vectors

1 In the **Home** toolbar, click **Add Plot Group** and choose **3D Plot Group**.

2 In the **Settings** window for **3D Plot Group**, type `Polarization Base Vectors` in the **Label** text field.

3 Click to expand the **Title** section. From the **Title type** list, choose **None**.

4 Locate the **Plot Settings** section. From the **View** list, choose **View 3D 3**.

Out-of-Plane Base Vector

1 Right-click **Polarization Base Vectors** and choose **Arrow Surface**.

2 In the **Settings** window for **Arrow Surface**, type `Out-of-Plane Base Vector` in the **Label** text field.

3 Click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)>Electromagnetic Waves, Frequency Domain>Ports>Polarization state>Jones base vectors>ewfd.eJROOPx_0_0,...,ewfd.eJROOPz_0_0 - Jones base vector on reflection side, out-of-plane direction, order [0,0]**.

4 Locate the **Arrow Positioning** section. In the **Number of arrows** text field, type `1`.

In-Plane Base Vector

1 Right-click **Out-of-Plane Base Vector** and choose **Duplicate**.

2 In the **Settings** window for **Arrow Surface**, type `In-Plane Base Vector` in the **Label** text field.

3 Click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)>Electromagnetic Waves, Frequency Domain>Ports>Polarization state>Jones base vectors>ewfd.eJRIPx_0_0,...,ewfd.eJRIPz_0_0 - Jones base vector on reflection side, in-plane direction, order [0,0]**.

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

5 Click to expand the **Inherit Style** section. From the **Plot** list, choose **Out-of-Plane Base Vector**.

6 Clear the **Color** check box.

Normalized Mode Wave Vector

1 Right-click **In-Plane Base Vector** and choose **Duplicate**.

2 In the **Settings** window for **Arrow Surface**, type `Normalized Mode Wave Vector` in the **Label** text field.

3 Locate the **Expression** section. In the **X component** text field, type `ewfd.kModex_1/ewfd.k`.

4 In the **Y component** text field, type `ewfd.kModey_1/ewfd.k`.

5 In the **Z component** text field, type `ewfd.kModez_1/ewfd.k`.

6 Locate the **Coloring and Style** section. From the **Color** list, choose **Blue**.

Boundary Normal

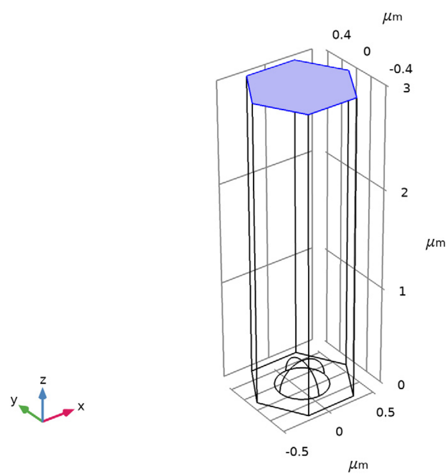
1 Right-click **Normalized Mode Wave Vector** and choose **Duplicate**.

2 In the **Settings** window for **Arrow Surface**, type `Boundary Normal` in the **Label** text field.

Selection 1

1 Right-click **Boundary Normal** and choose **Selection**, to only show the normal on the port boundary.

2 Select Boundary 4 only.



Boundary Normal

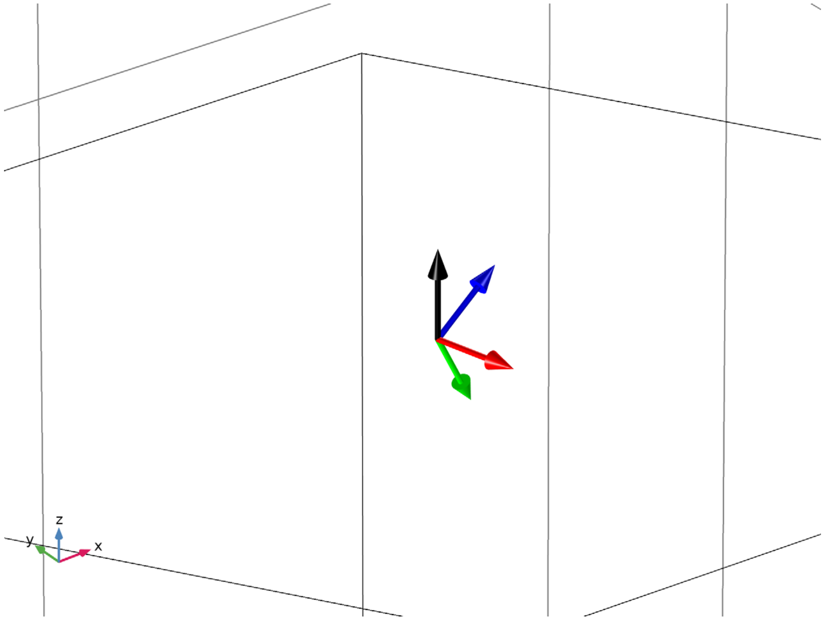
1 In the **Model Builder** window, click **Boundary Normal**.

2 In the **Settings** window for **Arrow Surface**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)>Electromagnetic Waves, Frequency Domain>Geometry and mesh>ewfd.nx,ewfd.ny, ewfd.nz - Normal vector**.

3 Locate the **Coloring and Style** section. From the **Color** list, choose **Black**.

4 In the **Polarization Base Vectors** toolbar, click **Plot**.

5 Zoom-in and move the plot, to make the vectors appear as in the picture below.



As shown, the out-of-plane base vector (red) is orthogonal to the plane spanned by the port normal (black) and the mode's wave vector (blue). The in-plane base vector (green) is parallel to the plane spanned by the port normal and the mode's wave vector.

Out-of-Plane Base Vector

Change the arrow expressions to visualize the behavior for mode $m = -1$, $n = -1$ to demonstrate that the base vectors are different for the different modes.

1 In the **Model Builder** window, click **Out-of-Plane Base Vector**.

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

3 In the **X component** text field, type `ewfd.eJROOPx_n1_n1`.

4 In the **Y component** text field, type `ewfd.eJROOPy_n1_n1`.

5 In the **Z component** text field, type `ewfd.eJROOPz_n1_n1`.

Here, the variable suffix `n1_n1` represents the mode number $m = -1$, $n = -1$.

In-Plane Base Vector

1 In the **Model Builder** window, click **In-Plane Base Vector**.

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

3 In the **X component** text field, type `ewfd.eJRIPx_n1_n1`.

4 In the **Y component** text field, type `ewfd.eJRIPy_n1_n1`.

5 In the **Z component** text field, type `ewfd.eJRIPz_n1_n1`.

Normalized Mode Wave Vector

1 In the **Model Builder** window, click **Normalized Mode Wave Vector**.

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

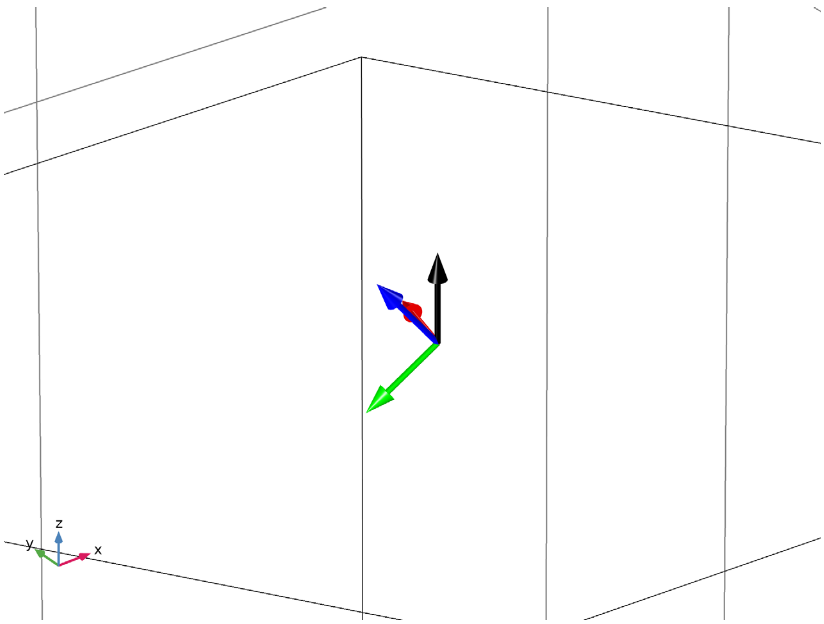
3 In the **X component** text field, type `ewfd.kModex_2/ewfd.k`.

4 In the **Y component** text field, type `ewfd.kModey_2/ewfd.k`.

5 In the **Z component** text field, type `ewfd.kModez_2/ewfd.k`.

Here, the variable suffix is the port name, not the mode number.

6 In the **Polarization Base Vectors** toolbar, click **Plot**.



As shown, the wave vector and the polarization vectors are different for this mode, compared to the vectors for the zero order mode.

ELECTROMAGNETIC WAVES, FREQUENCY DOMAIN (EWFD)

Port 1

Now, repeat the simulation for an incoming wave with p-polarization (the electric field polarized in the plane of incidence).

1 In the **Model Builder** window, under **Component 1 (comp1)>Electromagnetic Waves, Frequency Domain (ewfd)** click **Port 1**.
2 In the **Settings** window for **Port**, locate the **Port Mode Settings** section.
3 From the **Input quantity** list, choose **Magnetic field**.
4 Specify the $\mathbf{H}_0$ vector as

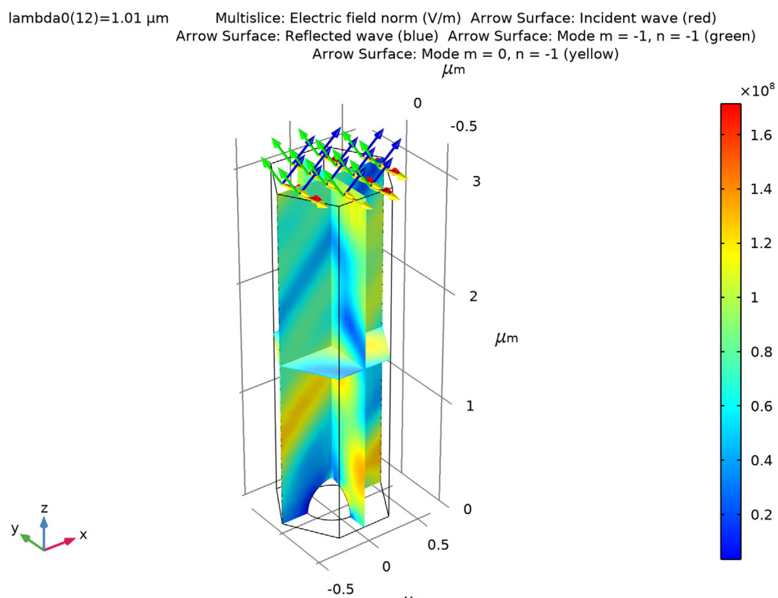
-H0*sin(phi)	x
H0*cos(phi)	y
0	z

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

RESULTS

Electric Field (ewfd)

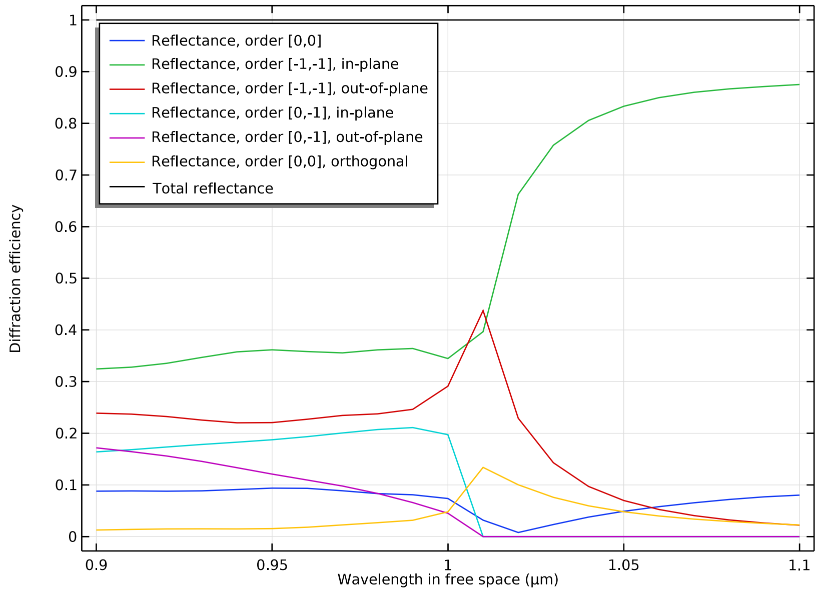
1 Click the **Zoom Extents** button in the **Graphics** toolbar, and verify that your plot look the same as Figure 8.



Reflectance (ewfd)

1 In the **Model Builder** window, click **Reflectance (ewfd)**.

2 In the **Reflectance (ewfd)** toolbar, click **Plot**, and verify that your plot look the same as Figure 9.

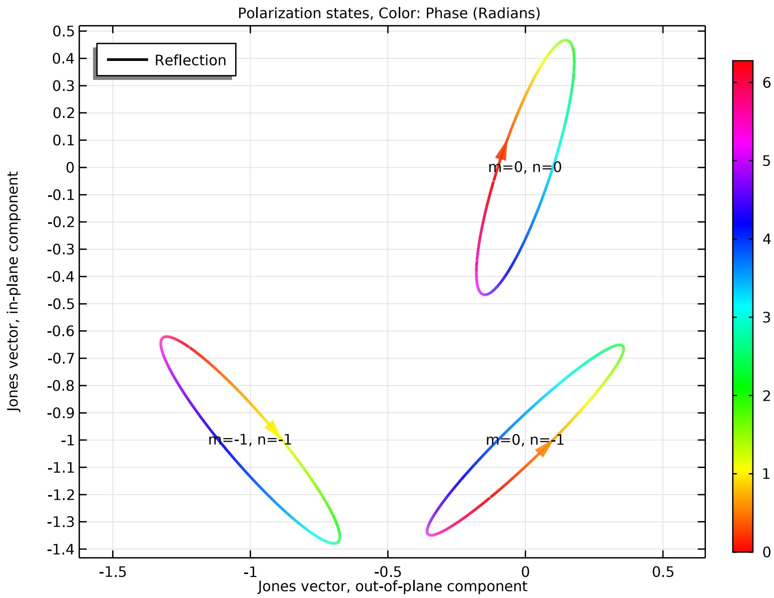


Polarization Plot (ewfd)

Finally, take a look at the polarization states when the input wave is p-polarized.

1 In the **Model Builder** window, click **Polarization Plot (ewfd)**.

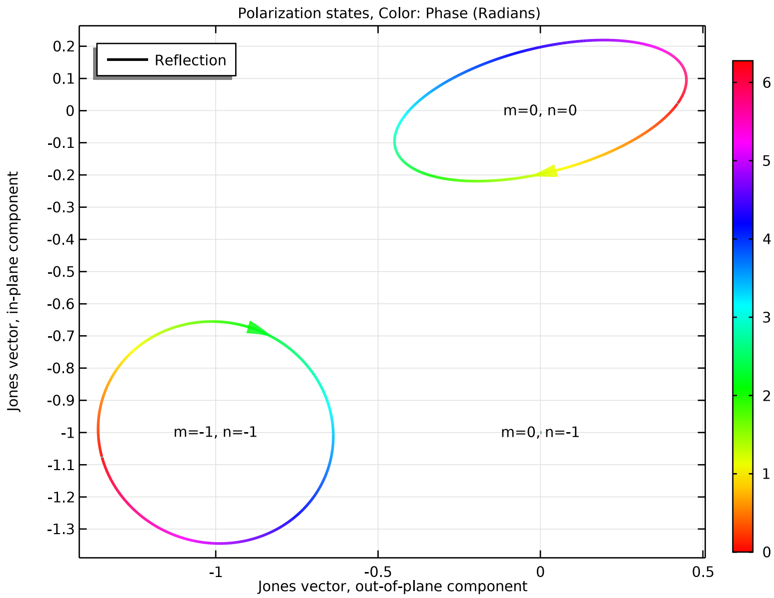
2 In the **Settings** window for **1D Plot Group**, click **Plot First**.



Also in this case, the polarization is elliptical for the different modes.

3 Locate the **Data** section. In the **Parameter values (lambda0 (µm))** list, select **1.01**.

4 In the **Polarization Plot (ewfd)** toolbar, click **Plot**.



At this wavelength, close the resonance, the polarization for the $m = 0$, $n = 0$ mode switches to almost out-of-plane polarization, whereas the $m = -1$, $n = -1$ mode has almost circular polarization. The relative magnitude of the Jones vector elements is also reflected in the diffraction efficiency plot above.