Model created in COMSOL Multiphysics 6.4

Euler Angle Rotation in Surface Acoustic Wave Modeling

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Introduction

In COMSOL Multiphysics, default material property matrices are defined with respect to crystal axes using the global X, Y, and Z coordinates (shown in the COMSOL Desktop geometry window). In general, surface acoustic wave (SAW) devices use different crystal cuts of piezoelectric materials that do not coincide with crystal axes, for examples, 128° *YX*-cut lithium niobate ($LiNbO_3$), AT-cut quartz, and 42° *YX*-cut lithium tantalate ($LiTaO_3$). When cut-specific data is not available, material property matrices can be derived from default material properties using Euler angle rotation. This tutorial presents examples of how Euler angle rotations are applied in three configurations using the 128° *YX*-cut $LiNbO_3$ to calculate eigenfrequencies and eigenmodes. Successful rotation can be confirmed quantitatively via the values of eigenfrequency or related phase velocity and qualitatively via the smooth and undistorted mode shapes.

Model Definition

In the *ZXZ* convention adopted by COMSOL Multiphysics, the Euler angles α, β, and γ define three successive rotations starting from the global axes (X, Y, Z) and ending at the local (crystal) axes (x, y, z). In this convention, the 128° *YX*-cut is defined in **Global Definitions** by α = `alpha_128 = 0°`, β = `beta_128 = -38°`, γ = `gamma_128 = 0°` as described in the Modeling Instructions. More information on the Euler angle rotation can be found in the documentation for the model Thickness Shear Mode Quartz Oscillator, also included in the MEMS Module Application Library.

Component 1, 3D

In the first example, a 3D component represents a unit cell with an *XZ* sagittal plane and wave propagation along the x-axis. In this configuration, the interdigital transducer (IDT) aperture would be defined along the y-axis. The geometry is shown in Figure 1. Define a **Rotated System** with α = `alpha_128`, β = `beta_128`, γ = `gamma_128` and select it as the coordinate system in the **Piezoelectric Material** Settings window. Set up Study 1 as an eigenfrequency study to calculate eigenfrequencies and eigenmodes for this configuration.

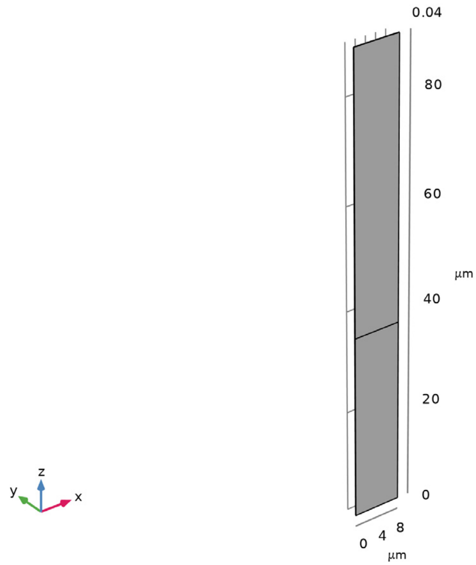

Figure 1: 3D geometry representing a unit cell with XZ sagittal plane and wave propagation along the x-axis.

Component 2, 3D

In the second example, a 3D component represents a unit cell with an *XY* sagittal plane, wave propagation along the *x*-axis, and the IDT aperture defined along the *z*-axis. Here Component 1 has been rotated around the *x*-axis by –90° as shown in Figure 2. Accordingly, define a **Rotated System** with α = `alpha_128`, β = `beta_128-90`°, γ = `gamma_128` and use it as the coordinate system in the **Piezoelectric Material** Settings window. Set up Study 2 as an eigenfrequency study.

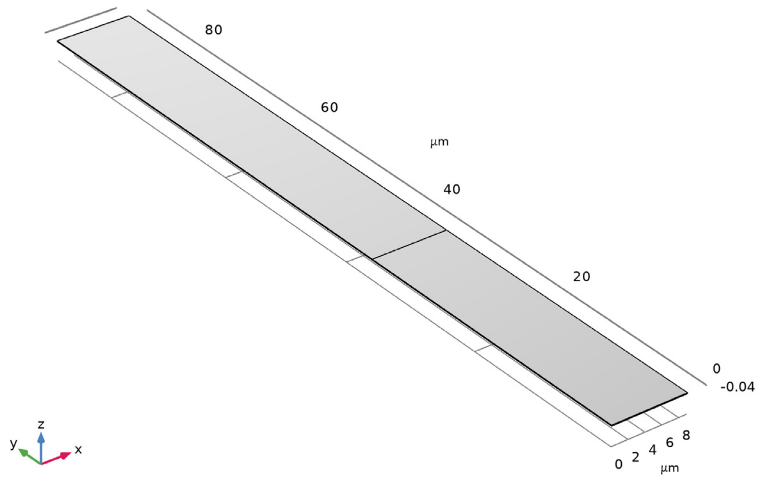

Figure 2: 3D geometry representing a unit cell with XY sagittal plane and wave propagation along the x-axis.

Component 3, 2D

The third example is a 2D version of the unit cell with an *XY* sagittal plane and wave propagation along the *x*-axis, as shown in Figure 3. Here the 128° *YX*-cut is again defined by a **Rotated System** with α = `alpha_128`, β = `beta_128-90°`, γ = `gamma_128`. Use it as the coordinate system in the **Piezoelectric Material** Settings window and set up Study 3 as an eigenfrequency study.

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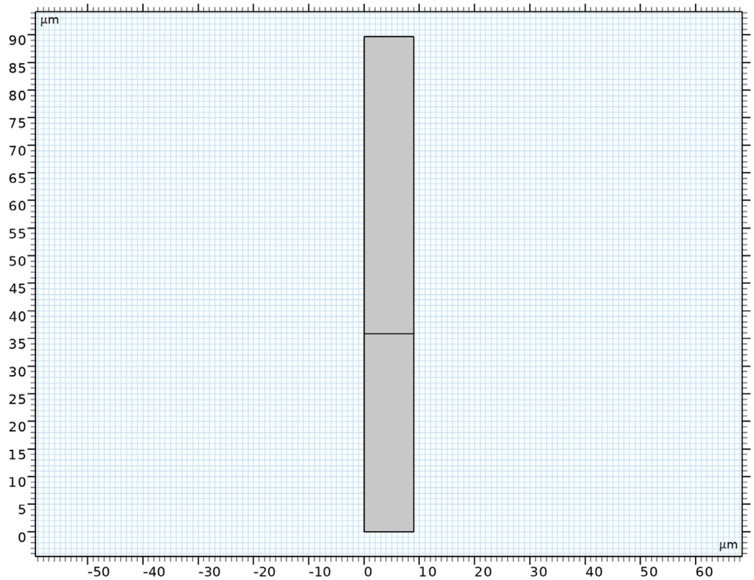


Figure 3: 2D component representing a unit cell with wave propagating along the x-axis and sagittal plane in the XZ-plane.

In the last example, you are given the material property matrices for 128° *YX*-cut $LiNbO_3$ in Table 1, Table 2, and Table 3. Add a second **Piezoelectric Material** model in the **Electrostatics** node under the 2D component. Instead of using a rotated system, copy and paste the values of the matrices directly into the table in the **Piezoelectric Material** Settings as shown as described in the Modeling Instructions. Set up Study 4 as an eigenfrequency study.

TABLE 1: ELASTICITY MATRIX FOR 128° XY-CUT LITHIUM NIOBATE

2.02897E11	6.99850E10	5.78425E10	1.28464E10	0	0
6.99850E10	1.93975E11	9.03296E10	9.31243E9	0	0
5.78425E10	9.03296E10	2.21158E11	8.00285E9	0	0
1.28464E10	9.31243E9	8.00285E9	7.53232E10	0	0
0	0	0	0	5.68597E10	-5.09155E9
0	0	0	0	-5.09155E9	7.79193E10

TABLE 2: COUPLING MATRIX FOR 128° XY-CUT LITHIUM NIOBATE

0	0	0	0	4.47243	0.27875
-1.88047	4.44672	-1.52214	0.06738	0	0
1.71492	-2.69210	2.31358	0.63381	0	0

TABLE 3: RELATIVE PERMITTIVITY FOR 128° XY-CUT LITHIUM NIOBATE

43.600	0	0
0	38.12668	-7.00553
0	-7.00553	34.63332

Results and Discussion

The results for Study 1 (Figure 4), Study 2 (Figure 5), and Study 3 and Study 4 (Figure 6) are identical. With correct rotations, variants of conversion from the default properties of $LiNb0_3$ to 128° *YX*-cut $LiNbO_3$ lead to identical results for mode shapes, eigenfrequencies, material data, and SAW velocity. It is recommended that such simple unit-cell verification is done before more complex configurations are investigated.

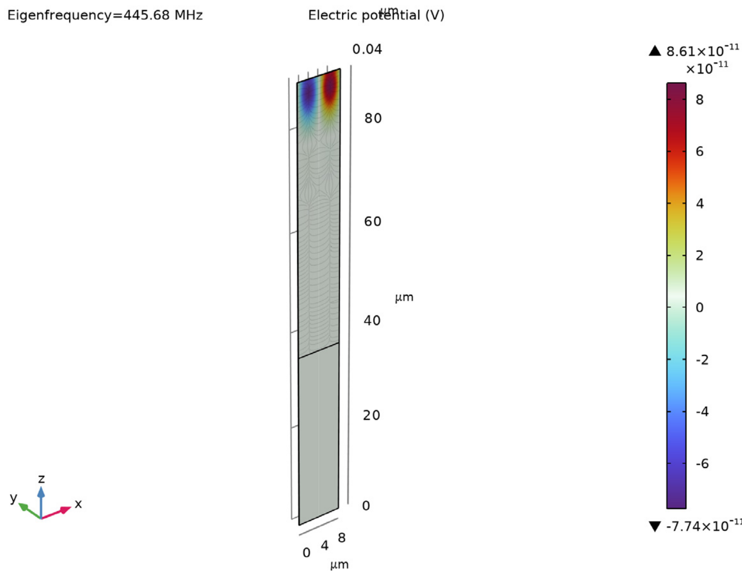


Figure 4: Result of Study 1 for Component 1 showing the eigenmode with eigenfrequency of 445.68 MHz.

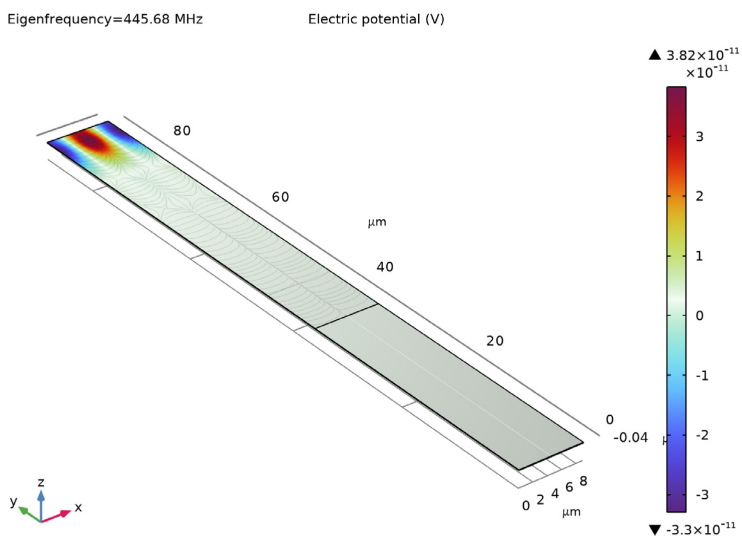


Figure 5: Result of Study 2 for Component 2 showing the eigenmode with eigenfrequency of 445.68 MHz.

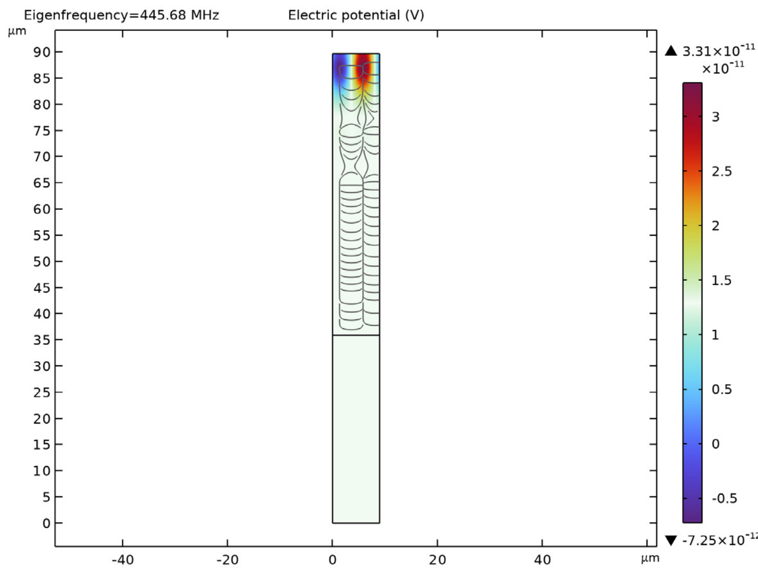


Figure 6: The result of Study 3 or Study 4 for Component 3 showing the eigenmode with eigenfrequency of 445.68 MHz.

Reference

1. K. Hashimoto, *Surface Acoustic Wave Devices in Telecommunications: Modeling and Simulation*, Springer-Verlag Berlin, Heidelberg, 2000; DOI: doi.org/10.1007/978-3-662-04223-6.

Application Library path: `MEMS_Module/Piezoelectric_Devices/saw_euler_angle_rotation`

Modeling Instructions

Start by creating a new 3D model with a **Piezoelectricity** multiphysics interface to model propagation along the *XZ*-plane. This first example shows how the Euler angle rotations are applied to obtain the material properties of the 128° YX-cut LiNbO3. Also select **Eigenfrequency** for the first study.

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 **AC/DC** > **Electromagnetics and Mechanics** > **Piezoelectricity** > **Piezoelectricity, Solid**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **Preset Studies for Selected Multiphysics** > **Eigenfrequency**.

6 Click **Done**.

GLOBAL DEFINITIONS

It is given that 128° YX-cut LiNbO3 is defined by α = alpha_128 = 0°, β = beta_128 = -38°, γ = gamma_128 = 0° based on the X-Z-X rotation sequence. Define and specify these and other parameters of the model in **Global Definitions**.

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
alpha_128	0[deg]	0 rad	Euler angle alpha
beta_128	-38[deg]	-0.66323 rad	Euler angle beta
gamma_128	0[deg]	0 rad	Euler angle gamma
lambdaG	8.97[um]	8.97E-6 m	Design period

Name	Expression	Value	Description
c_apr	3997.8[m/s]	3997.8 m/s	Expected free SAW velocity
f_apr	0.98*c_apr/lambdaG	4.3677E8 1/s	Initial guess for eigenfrequency

COMPONENT 1 3D X-PROPAGATION & XZ SAGITTAL PLANE

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

2 In the **Settings** window for **Component**, type `Component 1 3D X-Propagation & XZ Sagittal Plane` in the **Label** text field.

GEOMETRY 1

Use microns as the geometry unit. Create the geometry for the unit cell with the *XZ*-plane as the sagittal plane.

1 In the **Model Builder** window, under **Component 1 3D X-Propagation & XZ Sagittal Plane (comp1)** click **Geometry 1**.

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

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

Block 1 (blk1)

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

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

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

4 In the **Depth** text field, type `0.01*lambdaG`.

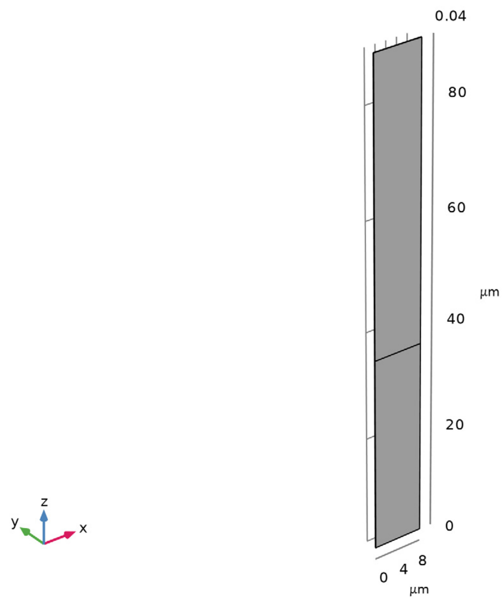
5 In the **Height** text field, type `10*lambdaG`.

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

Layer name	Thickness (µm)
Layer 1	4*lambdaG

7 In the **Geometry** toolbar, click **Build All**.

8 In the **Model Builder** window, click **Geometry 1**.



DEFINITIONS

Define operators that could be useful in results processing.

Maximum 1 (maxop1)

1. In the **Model Builder** window, expand the **Component 1 3D X-Propagation & XZ Sagittal Plane (comp1)** > **Definitions** node.
2. Right-click **Definitions** and choose **Nonlocal Couplings** > **Maximum**.
3. In the **Settings** window for **Maximum**, locate the **Source Selection** section.
4. From the **Selection** list, choose **All domains**.

Define a **Rotated System** for 128° YX-cut LiNbO3 in terms of the parameters alpha_128, beta_128 and gamma_128 and use it for the **Piezoelectric Material** feature under **Solid Mechanics** to compute the material properties for 128° YX-cut LiNbO3.

Rotated System 2 (sys2)

1. In the **Definitions** toolbar, click **Coordinate Systems** and choose **Rotated System**.
2. In the **Settings** window for **Rotated System**, locate the **Rotation** section.
3. Find the **Euler angles** subsection. In the α text field, type `alpha_128`.

4 In the β text field, type `beta_128`.

5 In the γ text field, type `gamma_128`.

Define a perfectly matched layer.

Perfectly Matched Layer 1 (pml1)

1 In the **Definitions** toolbar, click **Perfectly Matched Layer**.

2 Select Domain 1 only.

Add materials and assign the domains they belong to.

ADD MATERIAL

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

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

3 In the tree, select **Piezoelectric** > **Lithium Niobate**.

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

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

Specify the settings for the **Electrostatics** and **Solid Mechanics** interfaces in the unit cell.

ELECTROSTATICS (ES)

Periodic Condition 1

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

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

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog, type `2 5 8 9` in the **Selection** text field.

5 Click **OK**.

Periodic Condition 2

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

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

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog, type `1 4 10 11` in the **Selection** text field.

5 Click **OK**.

Use the previously defined rotated system in the **Piezoelectric Material** to compute the material properties for 128° YX-cut LiNbO3.

SOLID MECHANICS (SOLID)

Piezoelectric Material 1

1 In the **Model Builder** window, under **Component 1 3D X-Propagation & XZ Sagittal Plane (comp1)** > **Solid Mechanics (solid)** click **Piezoelectric Material 1**.

2 In the **Settings** window for **Piezoelectric Material**, locate the **Coordinate System Selection** section.

3 From the **Coordinate system** list, choose **Rotated System 2 (sys2)**.

Periodic Condition 1

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

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

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog, type 2 5 8 9 in the **Selection** text field.

5 Click **OK**.

Periodic Condition 2

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

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

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog, type 1 4 10 11 in the **Selection** text field.

5 Click **OK**.

Fixed Constraint 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Fixed Constraint**.

2 In the **Settings** window for **Fixed Constraint**, locate the **Boundary Selection** section.

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog, type 3 in the **Selection** text field.

5 Click **OK**.

Create a mesh for the unit cell with *XZ* sagittal plane.

MESH 1

Mapped 1

1 In the **Mesh** toolbar, click **More Generators** and choose **Mapped**.

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

3 Click Paste Selection.

4 In the **Paste Selection** dialog, type 2 5 in the **Selection** text field.

5 Click **OK**.

Distribution 1

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

2 In the **Settings** window for **Distribution**, locate the **Edge Selection** section.

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog, type 1 in the **Selection** text field.

5 Click **OK**.

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

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

Swept 1

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

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 lambdaG/20.

5 In the **Minimum element size** text field, type lambdaG/20.

6 In the **Model Builder** window, right-click **Mesh 1** and choose **Build All**.

For the second example, create a 3D component for a unit cell with *XY* sagittal plane starting by copying from **Component 1** and then rotating the geometry by -90°. Because the geometry (or the XY sagittal plane) has been rotated -90° from the first case, define **Rotated System** with beta = beta_128-90[deg] for 128° YX-cut LiNbO3.

COMPONENT 1 3D X-PROPAGATION & XZ SAGITTAL PLANE (COMP1)

1 In the **Model Builder** window, collapse the **Component 1 3D X-Propagation & XZ Sagittal Plane (comp1)** node.

2 In the **Model Builder** window, right-click **Component 1 3D X-Propagation & XZ Sagittal Plane (comp1)** and choose **Copy**.

COMPONENT 1 3D X-PROPAGATION & XZ SAGITTAL PLANE 1 (COMP2)

In the **Model Builder** window, right-click the root node and choose **Paste Multiple Items**.

COMPONENT 2 3D X-PROPAGATION & XY SAGITTAL PLANE

1 In the **Messages from Paste** dialog, click **OK**.

2 In the **Settings** window for **Component**, type `Component 2 3D X-Propagation & XY Sagittal Plane` in the **Label** text field.

DEFINITIONS (COMP2)

Rotated System 2 (sys4)

1 In the **Model Builder** window, under **Component 2 3D X-Propagation & XY Sagittal Plane (comp2)** > **Definitions** click **Rotated System 2 (sys4)**.

2 In the **Settings** window for **Rotated System**, locate the **Rotation** section.

3 Find the **Euler angles** subsection. In the β text field, type `beta_128-90[deg]`.

GEOMETRY 1

Rotate 1 (rot1)

1 In the **Model Builder** window, expand the **Component 2 3D X-Propagation & XY Sagittal Plane (comp2)** > **Geometry 1** node.

2 Right-click **Geometry 1** and choose **Transforms** > **Rotate**.

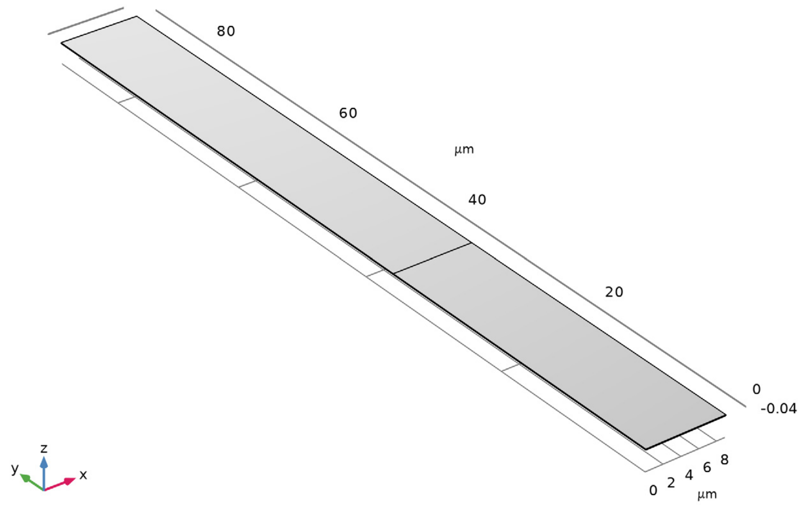
3 Select the object **blk1** only.

4 In the **Settings** window for **Rotate**, locate the **Rotation** section.

5 From the **Axis type** list, choose **x-axis**.

6 In the **Angle** text field, type `-90`.

7 Click **Build Selected**.



The third example is modeled in 2D by **Component 3**. Create a 2D component for the unit cell with *XY* sagittal plane and wave propagation in the X-direction, same as in the previous case. This model will use the same rotated system as the previous case.

ADD COMPONENT

In the **Model Builder** window, right-click the root node and choose **Add Component** > **2D**.

GEOMETRY 3

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

2 From the **Length unit** list, choose **µm**.

Rectangle 1 (r1)

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

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

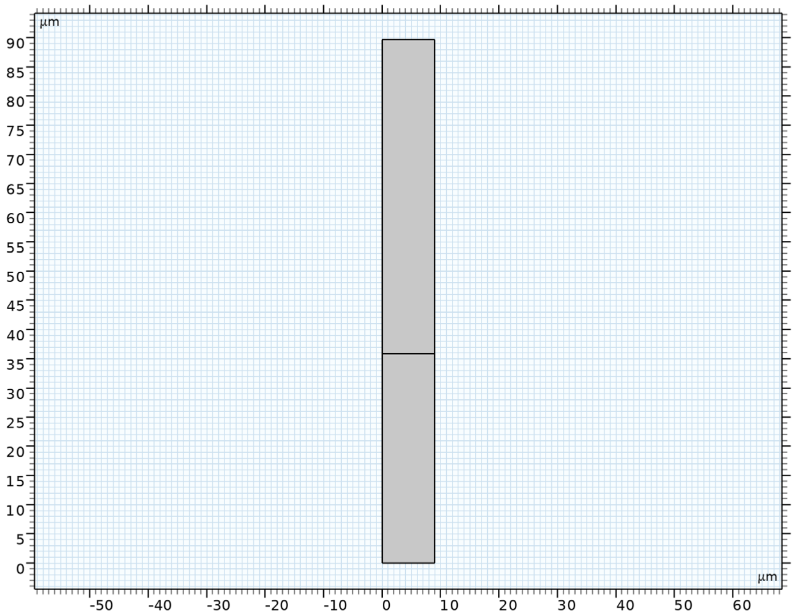
3 In the **Width** text field, type `lambdaG`.

4 In the **Height** text field, type `10*lambdaG`.

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

Layer name	Thickness (µm)
`Layer 1`	`4*lambdaG`

6 Click **Build Selected**.



DEFINITIONS (COMP3)

Maximum 3 (maxop3)

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

2 Click in the **Graphics** window and then press Ctrl+A to select both domains.

Define a rotated system for the 128° YX-cut LiNbO3.

Rotated System 6 (sys6)

1 In the **Definitions** toolbar, click **Coordinate Systems** and choose **Rotated System**.

2 In the **Settings** window for **Rotated System**, locate the **Rotation** section.

3 From the **Input method** list, choose **General rotation**.

4 Find the **Euler angles** subsection. In the α text field, type `alpha_128`.

5 In the β text field, type `beta_128-90[deg]`.

6 In the γ text field, type `gamma_128`.

Define a perfectly matched layer.

Perfectly Matched Layer 3 (pml3)

1 In the **Definitions** toolbar, click **Perfectly Matched Layer**.

2 Select Domain 1 only.

Add materials and assign the domains they belong to.

ADD MATERIAL

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

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

3 In the tree, select **Piezoelectric** > **Lithium Niobate**.

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

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

MATERIALS

Lithium Niobate (mat3)

Specify the settings for the **Electrostatics** and **Solid Mechanics** interfaces in the unit cell.

ADD PHYSICS

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

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

3 In the tree, select **AC/DC** > **Electromagnetics and Mechanics** > **Piezoelectricity** > **Piezoelectricity, Solid**.

4 Click the **Add to Component 3** button in the window toolbar.

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

ELECTROSTATICS 3 (ES3)

Periodic Condition 1

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

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

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog, type `1 3 6 7` in the **Selection** text field.

5 Click **OK**.

SOLID MECHANICS 3 (SOLID3)

For 2D geometry, enable Out-of-plane mode extension in **Solid Mechanics**.

1 In the **Model Builder** window, under **Component 3 (comp3)** click **Solid Mechanics 3 (solid3)**.

2 In the **Settings** window for **Solid Mechanics**, locate the **2D Approximation** section.

3 Select the **Out-of-plane mode extension (time-harmonic)** checkbox.

Piezoelectric Material Rotated

1 In the **Model Builder** window, under **Component 3 (comp3)** > **Solid Mechanics 3 (solid3)** click **Piezoelectric Material 1**.

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

3 Locate the **Coordinate System Selection** section. From the **Coordinate system** list, choose **Rotated System 6 (sys6)**.

In this last example, you are given the material property matrices for 128° YX-cut LiNbO3. To the 2D component, add a second **Piezoelectric Material** and define the material properties manually.

Piezoelectric Material Copy-Paste Data

1 In the **Physics** toolbar, click **Domains** and choose **Piezoelectric Material**.

2 In the **Settings** window for **Piezoelectric Material**, type `Piezoelectric Material Copy-Paste Data` in the **Label** text field.

3 Locate the **Domain Selection** section. Click **Paste Selection**.

4 In the **Paste Selection** dialog, type `1 2` in the **Selection** text field.

5 Click **OK**.

6 In the **Settings** window for **Piezoelectric Material**, locate the **Piezoelectric Material Properties** section.

7 From the c_E list, choose **User defined**. Specify the **associated** matrix as

2.02897E11	6.99850E10	5.78425E10	1.28464E10	0	0
6.99850E10	1.93975E11	9.03296E10	9.31243E9	0	0
5.78425E10	9.03296E10	2.21158E11	8.00285E9	0	0
1.28464E10	9.31243E9	8.00285E9	7.53232E10	0	0

0	0	0	0	5.68597E10	-5.09155E9
0	0	0	0	-5.09155E9	7.79193E10

8 From the e_{ES} list, choose **User defined**. Specify the **associated** matrix as

0	0	0	0	4.47243	0.27875
-1.88047	4.44672	-1.52214	0.06738	0	0
1.71492	-2.69210	2.31358	0.63381	0	0

9 From the ε_{rS} list, choose **User defined**. From the list, choose **Symmetric**.

10 Specify the ε_{rS} matrix as

43.600	0	0
0	38.12668	-7.00553
0	-7.00553	34.63332

11 From the ρ list, choose **User defined**. In the associated text field, type `4700[kg/m^3]`.

Periodic Condition 1

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

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

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog, type `1 3 6 7` in the **Selection** text field.

5 Click **OK**.

Fixed Constraint 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Fixed Constraint**.

2 In the **Settings** window for **Fixed Constraint**, locate the **Boundary Selection** section.

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog, type `2` in the **Selection** text field.

5 Click **OK**.

COMPONENT 3 2D X-PROPAGATION & XY SAGITTAL PLANE

1 In the **Model Builder** window, click **Component 3 (comp3)**.

2 In the **Settings** window for **Component**, type `Component 3 2D X-Propagation & XY Sagittal Plane` in the **Label** text field.

Create a mesh for the 2D unit cell.

MESH 3

Mapped 1

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

Distribution 1

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

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

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog, type `1` in the **Selection** text field.

5 Click **OK**.

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

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

Size

1 In the **Model Builder** window, under **Component 3 2D X-Propagation & XY Sagittal Plane (comp3)** > **Mesh 3** 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 `lambdaG/20`.

5 In the **Minimum element size** text field, type `lambdaG/20`.

6 Click **Build Selected**.

7 In the **Model Builder** window, right-click **Mesh 3** and choose **Build All**.

Set up the **Eigenfrequency** study to search around `f_apr` for the unit cell with *XZ* sagittal plane. For this study, disable Component 2 and Component 3.

STUDY 1: 3D X-PROPAGATION & XZ SAGITTAL PLANE

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

2 In the **Settings** window for **Study**, type `Study 1: 3D X-Propagation & XZ Sagittal Plane` in the **Label** text field.

Step 1: Eigenfrequency

1 In the **Model Builder** window, under **Study 1: 3D X-Propagation & XZ Sagittal Plane** click **Step 1: Eigenfrequency**.

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

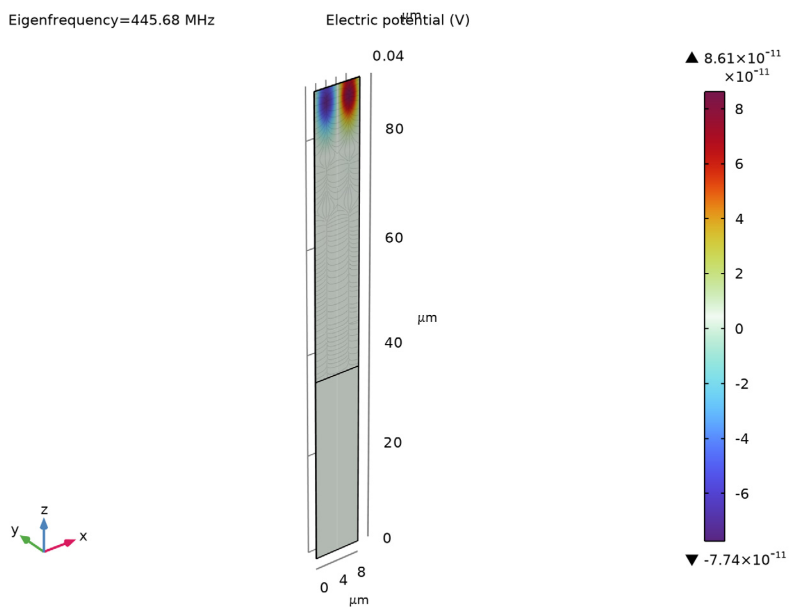
3 Select the **Desired number of eigenfrequencies** checkbox. In the associated text field, type `2`.

4 From the **Unit** list, choose **MHz**.

5 In the **Search for eigenfrequencies around shift** text field, type `f_apr`.

6 Locate the **Physics and Variables Selection** section. In the **Solve for** column of the table, clear the checkboxes for **Component 2 3D X-Propagation & XY Sagittal Plane (comp2)** and **Component 3 2D X-Propagation & XY Sagittal Plane (comp3)**.

7 In the **Study** toolbar, click **Compute**.



Add an **Eigenfrequency** study for the 3D unit cell with *XY* sagittal plane and set it up to search around `f_apr`. For this study, disable Component 1 and Component 3.

ADD STUDY

1 In the **Study** 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 Multiphysics > Eigenfrequency**.

4 Click the **Add Study** button in the window toolbar.

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

STUDY 2: 3D X-PROPAGATION & XY SAGITTAL PLANE

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

2 Select the **Desired number of eigenfrequencies** checkbox. In the associated text field, type `2`.

3 From the **Unit** list, choose **MHz**.

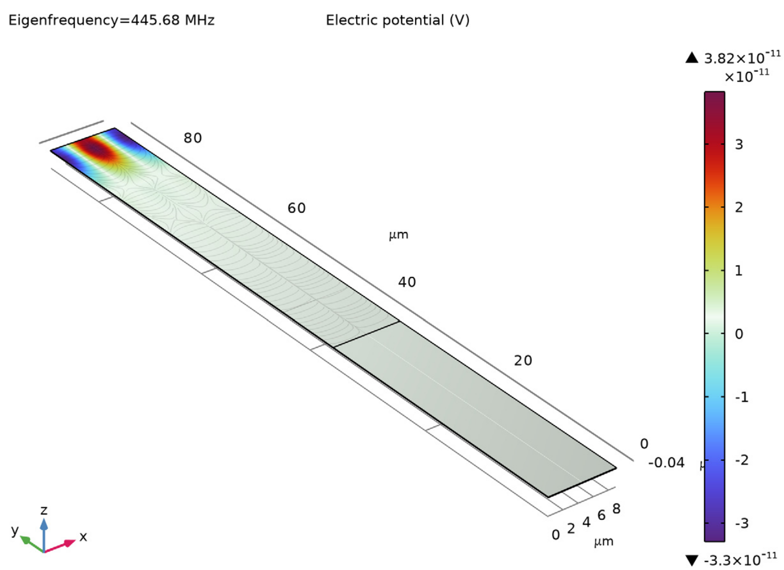
4 In the **Search for eigenfrequencies around shift** text field, type `f_apr`.

5 Locate the **Physics and Variables Selection** section. In the **Solve for** column of the table, clear the checkboxes for **Component 1 3D X-Propagation & XZ Sagittal Plane (comp1)** and **Component 3 2D X-Propagation & XY Sagittal Plane (comp3)**.

6 In the **Model Builder** window, click **Study 2**.

7 In the **Settings** window for **Study**, type `Study 2: 3D X-Propagation & XY Sagittal Plane` in the **Label** text field.

8 In the **Study** toolbar, click **Compute**.



Add an **Eigenfrequency** study for the 2D unit cell with *XY* sagittal plane and set it up to search around `f_apr`. For this study, disable Component 1 and Component 2 and Piezoelectric Material 2.

ADD STUDY

1 In the **Study** 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 Multiphysics** > **Eigenfrequency**.

4 Click the **Add Study** button in the window toolbar.

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

STUDY 3: 2D X-PROPAGATION & XY SAGITTAL PLANE, ROTATED

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

2 Select the **Desired number of eigenfrequencies** checkbox. In the associated text field, type `2`.

3 From the **Unit** list, choose **MHz**.

4 In the **Search for eigenfrequencies around shift** text field, type `f_apr`.

5 Locate the **Physics and Variables Selection** section. In the **Solve for** column of the table, clear the checkboxes for **Component 1 3D X-Propagation & XZ Sagittal Plane (comp1)** and **Component 2 3D X-Propagation & XY Sagittal Plane (comp2)**.

6 Select the **Modify model configuration for study step** checkbox.

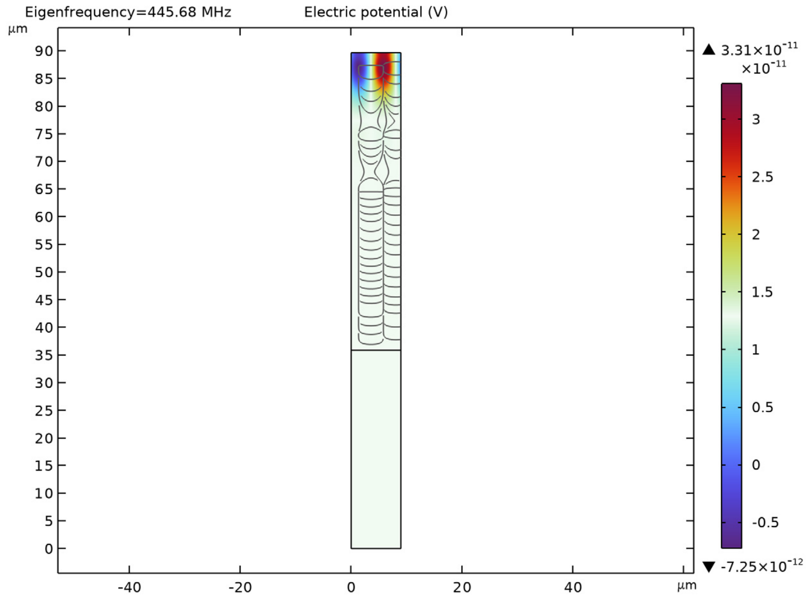
7 In the tree, select **Component 3 2D X-Propagation & XY Sagittal Plane (comp3)** > **Solid Mechanics 3 (solid3)** > **Piezoelectric Material Copy-Paste Data**.

8 Click **Disable**.

9 In the **Model Builder** window, click **Study 3**.

10 In the **Settings** window for **Study**, type `Study 3: 2D X-Propagation & XY Sagittal Plane, Rotated` in the **Label** text field.

11 In the **Study** toolbar, click **Compute**.



RESULTS

Electric Potential (es3)

Add an **Eigenfrequency** study for the 2D unit cell with *XY* sagittal plane as in the preceding study without disabling Piezoelectric Material Copy-Paste Data.

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 Multiphysics** > **Eigenfrequency**.

4 Click the **Add Study** button in the window toolbar.

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

STUDY 4

Step 1: Eigenfrequency

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

2 Select the **Desired number of eigenfrequencies** checkbox. In the associated text field, type `2`.

3 From the **Unit** list, choose **MHz**.

4 In the **Search for eigenfrequencies around shift** text field, type `f_apr`.

5 Locate the **Physics and Variables Selection** section. In the **Solve for** column of the table, clear the checkboxes for **Component 1 3D X-Propagation & XZ Sagittal Plane (comp1)** and **Component 2 3D X-Propagation & XY Sagittal Plane (comp2)**.

6 In the **Model Builder** window, click **Study 4**.

7 In the **Settings** window for **Study**, type `Study 4: 2D X-Propagation & XY Sagittal Plane, Copy-Paste Data` in the **Label** text field.

8 In the **Study** toolbar, click **Compute**.