Created in COMSOL Multiphysics 6.2

Porous Absorber

Introduction

This is a model of acoustic absorption by a porous acoustic open cell foam. In porous materials the sound propagates in a network of small interconnected pores. Because the dimensions of the pores are small, losses occur due to thermal conduction and viscous friction. Acoustic foams are used to sound proof rooms and ducts as well as to treat reverberation problems in rooms (see Ref. 1).

The aim of the model is to characterize the absorption properties — more specifically, the specific surface impedance and the absorption coefficient — of a layer of melamine foam in terms of sound incidence angle and frequency. The melamine foam contains an air inclusion. An analytical solution exists in the case where the layer is uniform. The model uses a 2D geometry of such a system.

Model Definition

Figure 1 depicts the geometry of the modeled system, in which an incident sound field hits the porous melamine foam layer at angle θ. An air inclusion, circular domain of radius a, is present in the porous layer. The incident wave has wave vector $\mathbf{k}$. In the figure, the dotted lined indicates the boundaries of the model domain. You only model a portion of width W and apply periodic Floquet boundary conditions on the left and right boundaries to extend the domain to infinity. The incident field is modeled by applying a background pressure field to the air domain. At the top, a perfectly matched layer (PML) domain is used to model an infinitely large air domain. The thickness of the porous melamine layer is $H_\mathrm{p} = 10$ cm and the height of the modeled air region is $H = 30$ cm. The height of the PML domain is H_pml.

Model the melamine foam using the Pressure Acoustics interface's Poroacoustics domain feature using the Johnson-Champoux-Allard model with a rigid frame. This is an equivalent fluid model for a rigid frame porous material, a so-called five parameter semi-empirical equivalent fluid model. See *About the Poroacoustics Models* in the *Acoustics Module User's Guide*. The surrounding fluid is air, and the material parameters for the foam are as listed in Table 1 (following Ref. 2, material sample number 31).

TABLE 1: MELAMINE FOAM MATERIAL PARAMETERS.

Symbol	**Value**	**Description**
ε_p	0.995	Porosity
R_f	10,500 Pa·s/m^2	Flow resistivity
s	0.49	Viscous characteristic length parameter
L_th	470 µm	Thermal characteristic length

TABLE 1: MELAMINE FOAM MATERIAL PARAMETERS.

Symbol	Value	Description
L_v	240 μm	Viscous characteristic length
τ	1.0059	Tortuosity factor

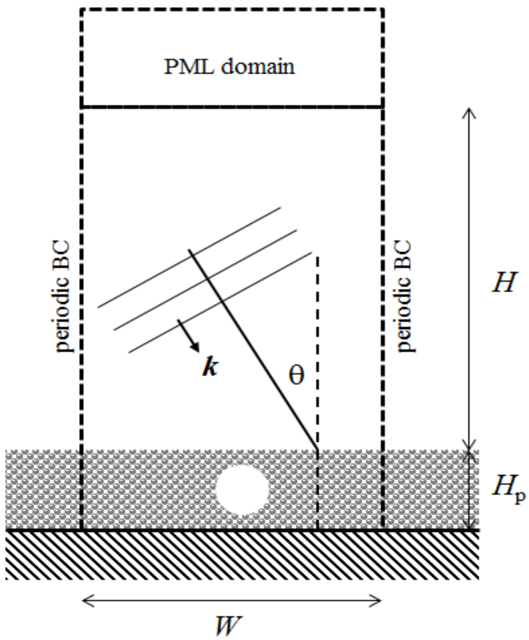


Figure 1: Geometry of the modeled system, the air inclusion has a radius a.

The incident background pressure field is given as

$$p_{\mathrm{inc}} = e^{-i(\mathbf{k} \cdot \mathbf{x})} \qquad \mathbf{k} = k_0(\sin\theta, -\cos\theta) \tag{1}$$

where θ is the incidence angle and k_0 is the wave number in the free field (air domain). The pressure p solved for in the model is the total field and the scattered field p_{scat} is given as $p_{\mathrm{scat}} = p - p_{\mathrm{inc}}$. Note that this expression for the scattered field is only valid in the air domain, as the incident field is not known a priori in the porous material.

Two parameters that characterize the absorption properties of the porous absorber are the specific surface impedance Z and the absorption coefficient α (see Ref. 1). The absorption coefficient, which represents the ratio of the absorbed and incident energy, is for a plane wave defined as

$$\alpha = 1 - |R|^2 \qquad R = \frac{p_{\mathrm{scat}}}{p_{\mathrm{inc}}} \tag{2}$$

where R is the pressure reflection coefficient that gives the ratio of the scattered to the incident pressure. This expression is valid as long as there are no higher-order diffraction modes; higher-order modes start to occur at a given cutoff frequency. In general the absorption coefficient can be defined through its energetic definitions as

$$\alpha = \frac{P_{\mathrm{scat}}}{P_{\mathrm{inc}}} \tag{3}$$

where P_{scat} is the total scattered power and P_{inc} is the total incident power. Both of these quantities can be computed from the intensity of the scattered and incident acoustic fields. The intensities of both fields exist as postprocessing variables when the **Calculate background and scattered field intensity** option is used in the **Background Pressure Field** feature. Remember that in the nomenclature used in the Acoustics Module the incident field is called the background field, when setting up the model.

The surface specific impedance (normalized by the plane wave characteristic impedance) is defined as

$$Z = \frac{1}{\rho c}\frac{p}{u_{\mathrm{n}}} \tag{4}$$

where ρ is the density of air, c is the speed of sound, and $u_{\mathrm{n}} = \mathbf{u}\cdot\mathbf{n}$ is the normal velocity at the surface of the melamine layer. When computing the expression it will be taken as the average at the surface of the porous layer. When averaging it is important to average the ratio p/u_{n} and not average p and u_{n} separately, the latter leads to incorrect results.

Both the absorption coefficient and the surface normal impedance are dependent on frequency and on the incidence angle.

UNIFORM POROUS LAYER SOLUTION

In the case of a uniform porous layer (with no air inclusions) of thickness H_{p} backed by a sound hard wall, an analytical solution exists for the surface impedance, reflection coefficient, and absorption coefficient (see Ref. 1). The surface normal impedance (normalized by the characteristic plane wave impedance) is given by

$$
\begin{aligned}
Z_{\text{ana}} &= \frac{1}{\rho c}\frac{-iZ_{\text{c}}k_{\text{c}}}{k_{\text{x}}}\cot(k_{\text{x}}H_{\text{p}}) \\
k_{\text{x}} &= \sqrt{k_{\text{c}}^2 - k_{\text{y}}^2} \\
k_{\text{y}} &= k_0\sin(\theta)
\end{aligned}
\tag{5}
$$

where a subscript "c" represents complex-valued impedance and wave number variables from the Poroacoustic domain. From the normal impedance the absorption coefficient is deduced.

Results and Discussion

Figure 2 and Figure 3 plot the scattered and total pressure fields for an incidence angle of 45° and the frequency f = 10 kHz. Notice how the wave is absorbed in the porous layer.

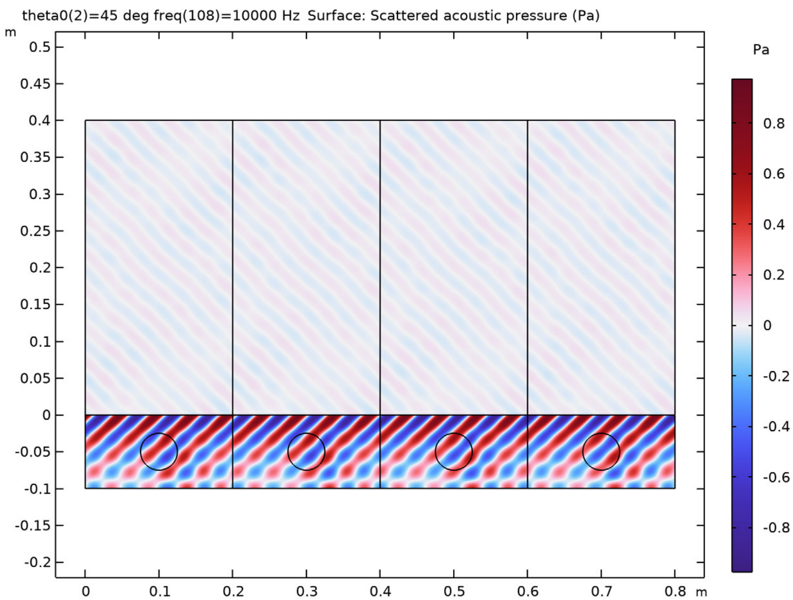


Figure 2: Scattered pressure field for an incidence angle of 45⁰ and frequency f = 10 kHz.

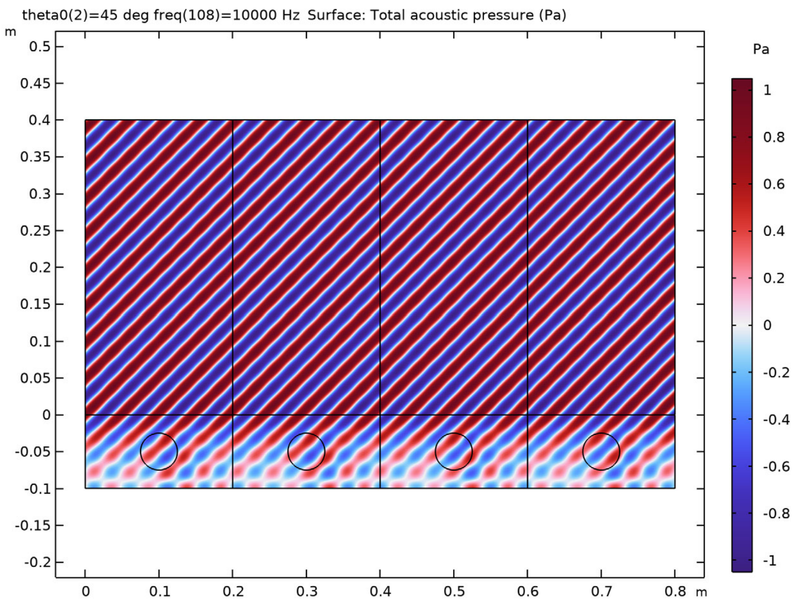


Figure 3: Total acoustic pressure for an incidence angle of 45^0 and frequency f = 10 kHz.

Figure 4 depicts the acoustic pressure (the real part) at the surface of the porous melamine layer for two angles of incidence. Figure 5 plots the specific acoustic impedance at the surface of the porous absorber (computed as the average across the surface). Figure 6 shows the absorption coefficient; comparing the energy based absorption coefficient (Equation 3) to the coefficient computed based on the reflection coefficient (Equation 2), and the analytical solution of a uniform porous layer. Finally, Figure 7 depicts the absorption coefficient for normal incidence in octave and 1/3 octave bands. The **Octave Band** plot feature automatically creates tables, which can be found under **Results>Tables** and easily exported as text or spreadsheet files.

Looking closely at Figure 6, it can be seen that the absorption coefficient based on the reflection coefficient, which assumes pure plane waves, start to differ slightly from the energy based values, at specific frequencies (1000 Hz and 1700 Hz, depending on the incidence angle). These are the cut on/off frequencies for higher order diffraction modes. In this particular setup, the difference is not large as the properties of the air inclusion are relatively close to the porous material. For other configurations, for example, having solid inclusions, the difference could be larger. The energy based absorption coefficient represents the actual absorbed energy metric.

The dependency of the surface specific impedance and/or absorption coefficient on incidence angle and frequency is important for modeling absorbers as impedance boundary conditions in, for example, a Ray Acoustics model. In larger model systems the present model could be used as a “submodel” to determine appropriate impedance boundary conditions. The real part of the impedance (the resistance) is associated with energy loss whereas the imaginary part (the reactance) is associated with phase changes of the field. The reciprocal value of the impedance is the admittance.

In this system, the absorption coefficient approaches 1 for increasing frequency. This corresponds to the frequency where the product between the porous absorber height H_p and $k_y\pi^{-1}$ of the incident wave is equal to one. This is where half a wavelength fits into the absorbing layer.

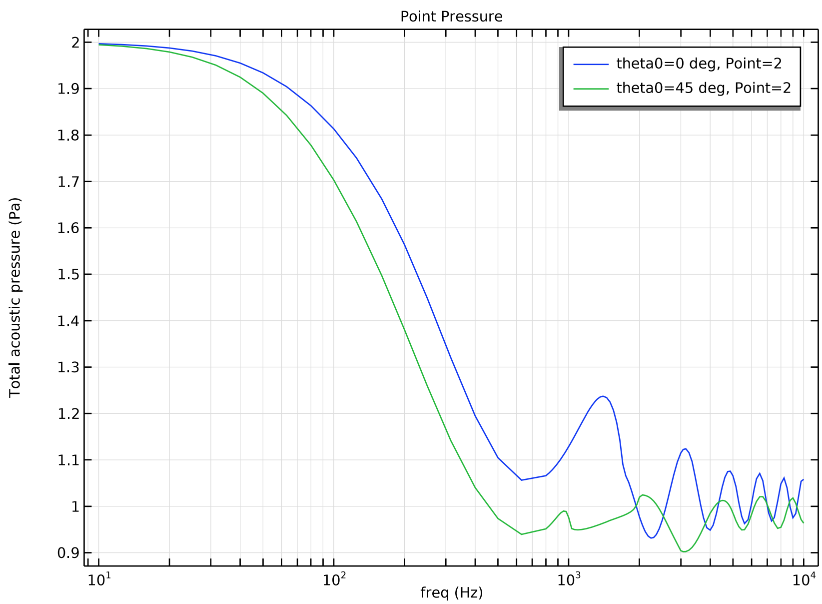


Figure 4: Sound pressure level at the surface of the porous absorber.

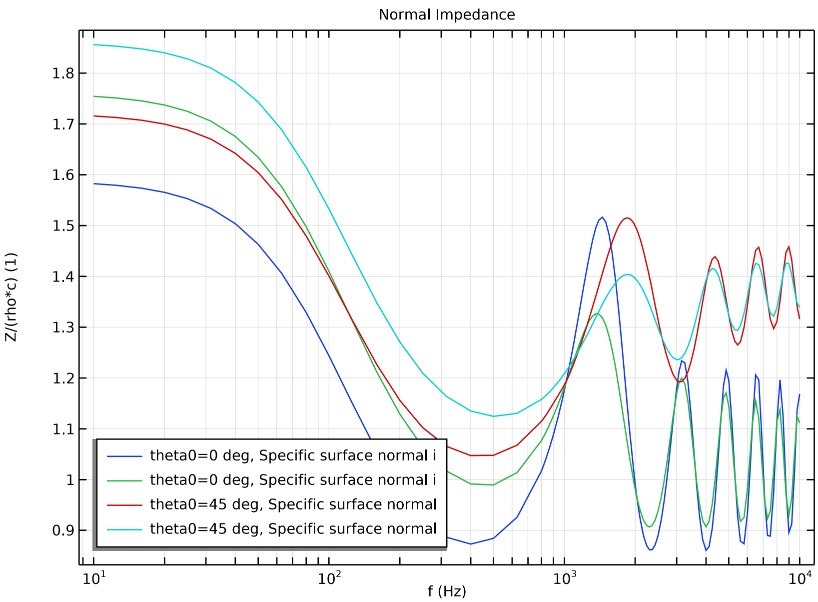


Figure 5: Specific acoustic impedance at the surface of the porous absorber.

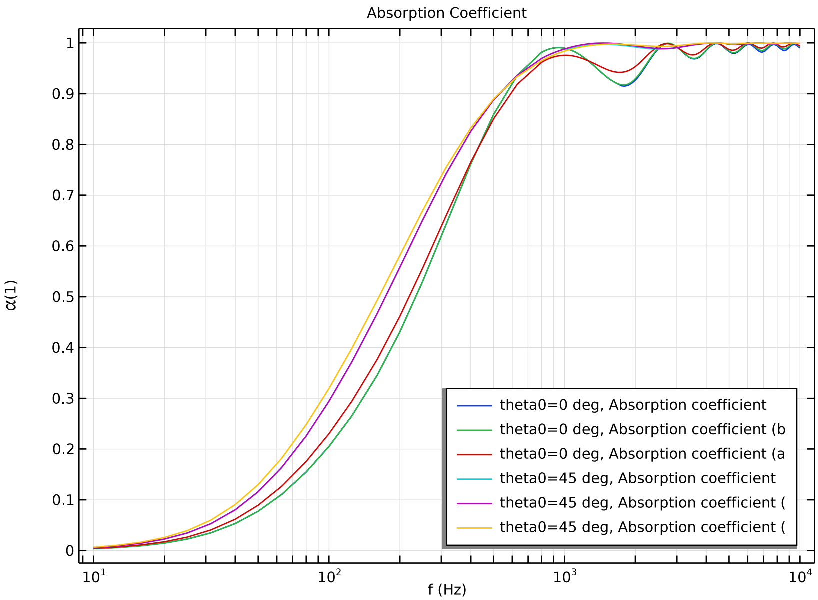


Figure 6: Absorption coefficient for the porous melamine absorber as function of frequency and incidence angle. Compared to the reflection coefficient based expression and the analytical solution of a uniform layer.

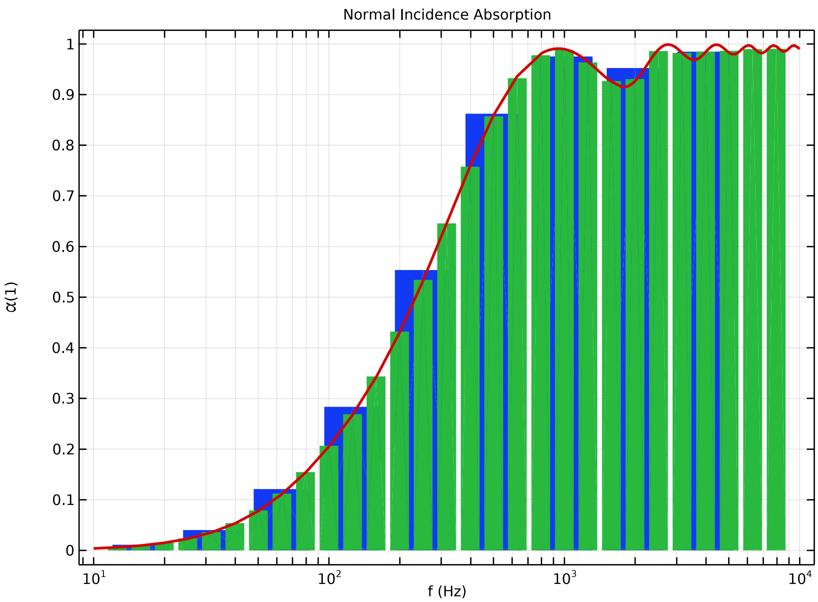


Figure 7: Absorption coefficient of the porous melamine absorber for normal incidence in octave bands, 1/3 octave bands, and continuous frequency.

Notes About the COMSOL Implementation

PERIODIC FLOQUET BOUNDARY CONDITION

Apply a periodic Floquet boundary condition to model an infinite periodic structure. The periodicity is determined by the wave number of the background (incident) pressure field. The relation between the pressure at the left and right boundaries of the model domain is

$$p(\mathbf{x}) = p(\mathbf{x}+\mathbf{d})e^{-i(\mathbf{k}\cdot\mathbf{d})} \tag{6}$$

where $\mathbf{d} = (W,\ 0)$ is a vector extending from the left to the right boundary and $\mathbf{k}$ is the wave vector defined in Equation 1. COMSOL Multiphysics automatically calculates the vector $\mathbf{d}$ when applying the Floquet periodicity.

VISUALIZE PERIODIC SOLUTION

To visualize the periodic solution, create an Array 2D dataset and enable **Floquet-Bloch periodicity** under **Advanced** section. Enter the same **Wave vector** as used in the periodic conditions.

COMPARING TO THE ANALYTICAL SOLUTION

In the results section the simulated absorption coefficient and surface impedance are compared to the analytical solution of a uniform porous layer. To make a verification of the model simply select the inclusion (the circular air domain) as a Poroacoustic domain and run the model again. You will find that the analytical and model results show perfect agreement.

References

1. T.J. Cox and P. D'Antonio, *Acoustic Absorbers and Diffusers, Theory, Design and Applications,* 2nd ed., Taylor and Francis, 2009.

2. N. Kino and T. Ueno, "Comparison between characteristic lengths and fiber equivalent diameter in glass fiber and melamine foam materials of similar flow resistivity", *J. App. Acoustics*, vol. 69, pp. 325–331, 2008.

Application Library path: `Acoustics_Module/Building_and_Room_Acoustics/porous_absorber`

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 **Acoustics>Pressure Acoustics>Pressure Acoustics, Frequency Domain (acpr)**.
3. Click **Add**.
4. Click **Study**.
5. In the **Select Study** tree, select **General Studies>Frequency Domain**.
6. Click **Done**.

GLOBAL DEFINITIONS

Load the parameters for the model. The list of parameters include geometry definitions, definitions used in the mesh, and material parameters for the melamine foam.

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 `porous_absorber_parameters.txt`.

GEOMETRY 1

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`.
4. In the **Height** text field, type `H+Hpml`.
5. Click to expand the **Layers** section. Clear the **Layers on bottom** check box.
6. Select the **Layers on top** check box.
7. In the table, enter the following settings:

Layer name	Thickness (m)
`Layer 1`	`Hpml`

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`.
4. In the **Height** text field, type `Hp`.
5. Locate the **Position** section. In the **y** text field, type `-Hp`.

Circle 1 (c1)

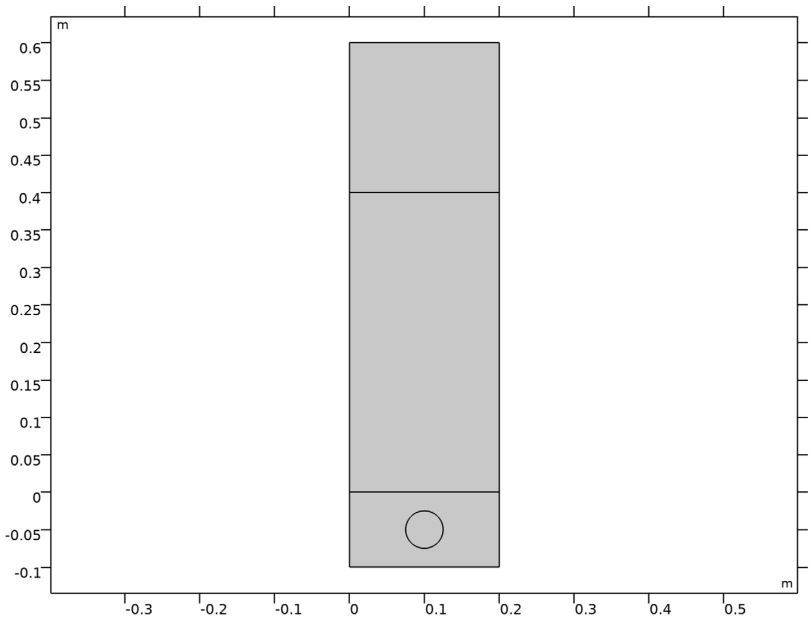
1. In the **Geometry** toolbar, click **Circle**.
2. In the **Settings** window for **Circle**, locate the **Size and Shape** section.
3. In the **Radius** text field, type `a`.
4. Locate the **Position** section. In the **x** text field, type `W/2`.

5 In the **y** text field, type `-Hp/2`.

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

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

The geometry should look like that in the figure below.



DEFINITIONS

Load the expressions defining the surface impedance and absorption coefficient, see Equation 2 and Equation 4, from a file.

Variables 1

1 In the **Home** toolbar, click **Variables** and choose **Local Variables**.

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

3 Click **Load from File**.

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

Load the expressions defining the analytical expressions for a single porous layer with a sound hard backing, see Equation 5.

Variables 2

1 In the **Home** toolbar, click **Variables** and choose **Local Variables**.

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

3 Click **Load from File**.

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

Define two nonlocal integration couplings that act on points in the geometry. You will use them later to map (or probe) values from these points. One in the porous domain and one in the air domain.

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 **Point**.

4 Select Point 1 only.

Integration 2 (intop2)

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 **Point**.

4 Select Point 3 only.

Define an average and integration coupling on the porous-air interface to help compute the average reflection coefficient as well as incident and reflected powers.

Average 1 (aveop1)

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

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

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

4 Select Boundary 4 only.

Integration 3 (intop3)

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 Select Boundary 4 only.

Now proceed to set up the material properties. Add air as the default domain material and create a new material to define the melamine foam porosity.

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.

MATERIALS

Melamine Foam

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 `Melamine Foam` in the **Label** text field.

3 Select Domain 1 only.

4 Click to expand the **Material Properties** section. In the **Material properties** tree, select **Basic Properties>Porosity**.

5 Click **Add to Material**.

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

Property	Variable	Value	Unit	Property group
Porosity	epsilon	`epsilonP0`	1	Basic

7 Locate the **Material Properties** section. In the **Material properties** tree, select **Acoustics>Poroacoustics Model>Thermal characteristic length (Lth)**.

8 Click **Add to Material**.

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

Property	Variable	Value	Unit	Property group
Flow resistivity	Rf_iso ; Rfii = Rf_iso, Rfij = 0	`Rf0`	Pa·s/m²	Poroacoustics model
Thermal characteristic length	Lth	`Lth0`	m	Poroacoustics model
Viscous characteristic length	Lv_iso ; Lvii = Lv_iso, Lvij = 0	`Lv0`	m	Poroacoustics model
Tortuosity factor	tau_iso ; tauii = tau_iso, tauij = 0	`tau0`	1	Poroacoustics model

Notice that the parameter for the tortuosity is called tau0, not to be confused with the material property of the static viscous tortuosity.

Now set up the physics and the boundary conditions. First, define the incident background pressure field, see Equation 2, then the Floquet condition, see Equation 6, and finally porous material properties for the melamine foam.

DEFINITIONS

Perfectly Matched Layer 1 (pml1)

1. In the **Definitions** toolbar, click **Perfectly Matched Layer**.
2. Select Domain 3 only.
3. In the **Settings** window for **Perfectly Matched Layer**, locate the **Scaling** section.
4. From the **Coordinate stretching type** list, choose **Rational**.
5. In the **PML scaling factor** text field, type `1/cos(theta0)`.

   It is recommended to modify the scaling of the PML to account for the direction of the plane wave.

PRESSURE ACOUSTICS, FREQUENCY DOMAIN (ACPR)

Background Pressure Field 1

1. In the **Model Builder** window, under **Component 1 (comp1)** right-click **Pressure Acoustics, Frequency Domain (acpr)** and choose **Background Pressure Field**.
2. Select Domain 2 only.

3 In the **Settings** window for **Background Pressure Field**, locate the **Background Pressure Field** section.

4 In the p_0 text field, type 1.

5 From the c list, choose **From material**.

6 Specify the $\mathbf{e}_k$ vector as

kx_e	x
ky_e	y

7 Select the **Calculate background and scattered field intensity** check box.

8 From the ρ list, choose **From material**.

Now, add the poroacoustic domain defining the melamine foam.

Poroacoustics 1

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

2 Select Domain 1 only.

3 In the **Settings** window for **Poroacoustics**, locate the **Poroacoustics Model** section.

4 From the **Poroacoustics model** list, choose **Johnson-Champoux-Allard (JCA)**.

5 Locate the **Fluid Properties** section. From the **Fluid material** list, choose **Air (mat1)**.

It is good practice to add a periodic condition for each type of domain, in this case, one for the PML, one for the pressure acoustics, and one for the porous domain. This is especially the case when using a background pressure field.

Periodic Condition 1

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

2 Select Boundaries 1 and 8 only.

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

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

5 Specify the $\mathbf{k}_\mathrm{F}$ vector as

kx	x
ky	y

Periodic Condition 2

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

2 Select Boundaries 3 and 9 only.

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

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

5 Specify the $\mathbf{k}_F$ vector as

kx	x
ky	y

Periodic Condition 3

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

2 Select Boundaries 5 and 10 only.

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

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

5 Specify the $\mathbf{k}_F$ vector as

kx	x
ky	y

MESH 1

Identical Mesh 1

1 In the **Mesh** toolbar, click **More Attributes** and choose **Identical Mesh**.

2 Select Boundary 1 only.

3 In the **Settings** window for **Identical Mesh**, locate the **Second Entity Group** section.

4 Click to select the **Activate Selection** toggle button.

5 Select Boundary 8 only.

Free Triangular 1

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

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

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

4 Select Domains 1 and 4 only.

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 `lambda_min/5`.

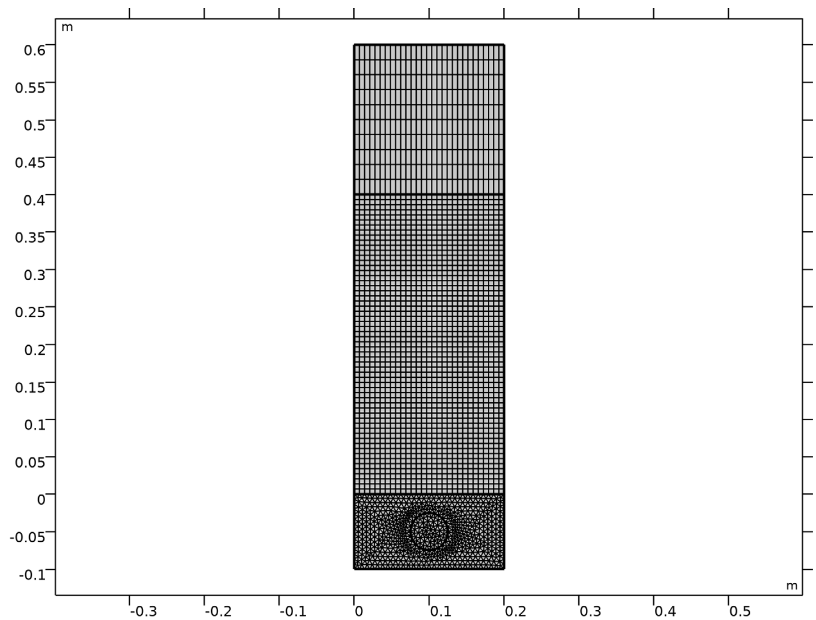
This mesh resolves the smallest wavelength of the study `lambda_min` with 5 elements.

Mapped 1

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

Distribution 1

1 Right-click **Mapped 1** and choose **Distribution**.
2 Select Boundaries 5 and 10 only.
3 In the **Settings** window for **Distribution**, locate the **Distribution** section.
4 In the **Number of elements** text field, type `10`.
5 Click **Build All**.
6 In the **Model Builder** window, click **Mesh 1**.



STUDY 1

Step 1: Frequency Domain

1 In the **Model Builder** window, under **Study 1** click **Step 1: Frequency Domain**.
2 In the **Settings** window for **Frequency Domain**, locate the **Study Settings** section.

3 Click **Range**.

4 In the **Range** dialog box, choose **ISO preferred frequencies** from the **Entry method** list.

5 In the **Start frequency** text field, type `10`.

6 In the **Stop frequency** text field, type `800`.

7 From the **Interval** list, choose **1/3 octave**.

8 Click **Replace**.

9 In the **Settings** window for **Frequency Domain**, locate the **Study Settings** section.

10 Click **Range**.

11 In the **Range** dialog box, type `825` in the **Start frequency** text field.

12 In the **Stop frequency** text field, type `10000`.

13 From the **Interval** list, choose **1/24 octave**.

14 Click **Add**.

This frequency request uses ISO preferred sequences with a third octave spacing for low frequencies and a 24th octave spacing at higher frequencies. Add a parametric sweep over the incidence angle `theta0` for the values 0^o and 45^o.

Parametric Sweep

1 In the **Study** toolbar, click **Parametric Sweep**.

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

3 Click **Add**.

4 In the table, enter the following settings:

Parameter name	Parameter value list
theta0 (Incident wave angle)	`0[deg] 45[deg]`

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

Create an array dataset that will help you plot the Floquet periodic solution on several unit cells. Add a selection to not show the unphysical solution in the PML domain.

RESULTS

Study 1/Parametric Solutions 1 (sol2)

In the **Model Builder** window, expand the **Results>Datasets** node, then click **Study 1/ Parametric Solutions 1 (sol2)**.

Selection

1 In the **Results** toolbar, click **Attributes** and choose **Selection**.

2 In the **Settings** window for **Selection**, locate the **Geometric Entity Selection** section.

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

4 Select Domains 1, 2, and 4 only.

Array 2D 1

1 In the **Results** toolbar, click **More Datasets** and choose **Array 2D**.

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

3 From the **Dataset** list, choose **Study 1/Parametric Solutions 1 (sol2)**.

4 Locate the **Array Size** section. In the **X size** text field, type `4`.

Enable **Floquet-Bloch periodicity** and enter the **Wave vector** to visualize the periodic solution.

5 Click to expand the **Advanced** section. Select the **Floquet-Bloch periodicity** check box.

6 Find the **Wave vector** subsection. In the **X** text field, type `kx`.

7 In the **Y** text field, type `ky`.

Total Acoustic Pressure

1 In the **Model Builder** window, under **Results** click **Acoustic Pressure (acpr)**.

2 In the **Settings** window for **2D Plot Group**, type `Total Acoustic Pressure` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Array 2D 1**.

Surface 1

1 In the **Model Builder** window, expand the **Total Acoustic Pressure** node, then click **Surface 1**.

2 In the **Total Acoustic Pressure** toolbar, click **Plot**.

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

Compare the resulting plot with that in Figure 3.

Now change the incidence angle from 45^o to 0^o.

Total Acoustic Pressure

1 In the **Model Builder** window, click **Total Acoustic Pressure**.

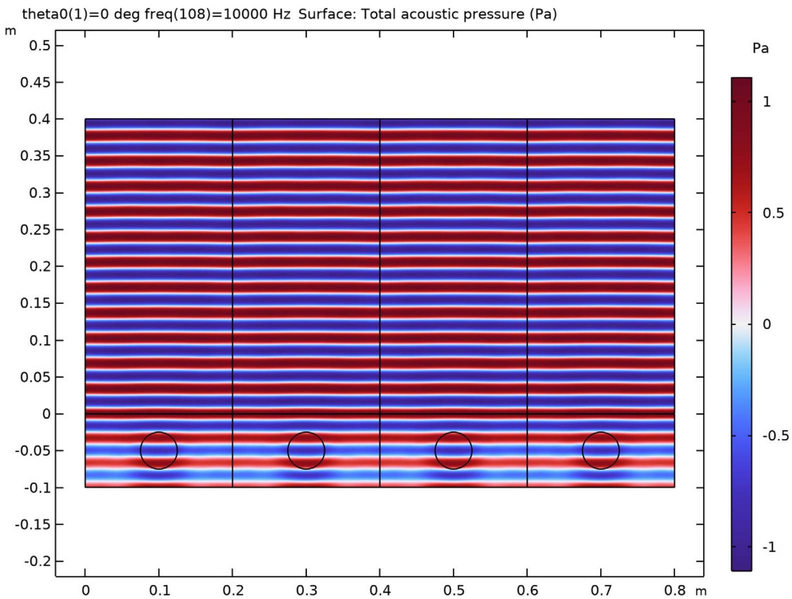
2 In the **Settings** window for **2D Plot Group**, locate the **Data** section.

3 From the **Parameter value (theta0 (deg))** list, choose **0**.

4 In the **Total Acoustic Pressure** toolbar, click **Plot**.

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

The result should look like that in the following figure.



6 Right-click **Total Acoustic Pressure** and choose **Duplicate**.

Scattered Acoustic Pressure

1 In the **Model Builder** window, under **Results** click **Total Acoustic Pressure 1**.

2 In the **Settings** window for **2D Plot Group**, type `Scattered Acoustic Pressure` in the **Label** text field.

Now, plot the scattered acoustic pressure.

Surface 1

1 In the **Model Builder** window, expand the **Scattered Acoustic Pressure** node, then click **Surface 1**.

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

3 In the **Expression** text field, type `acpr.p_s`.

Scattered Acoustic Pressure

1 In the **Model Builder** window, click **Scattered Acoustic Pressure**.

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

3 From the **Parameter value (theta0 (deg))** list, choose **45**.

4 In the **Scattered Acoustic Pressure** toolbar, click **Plot**.

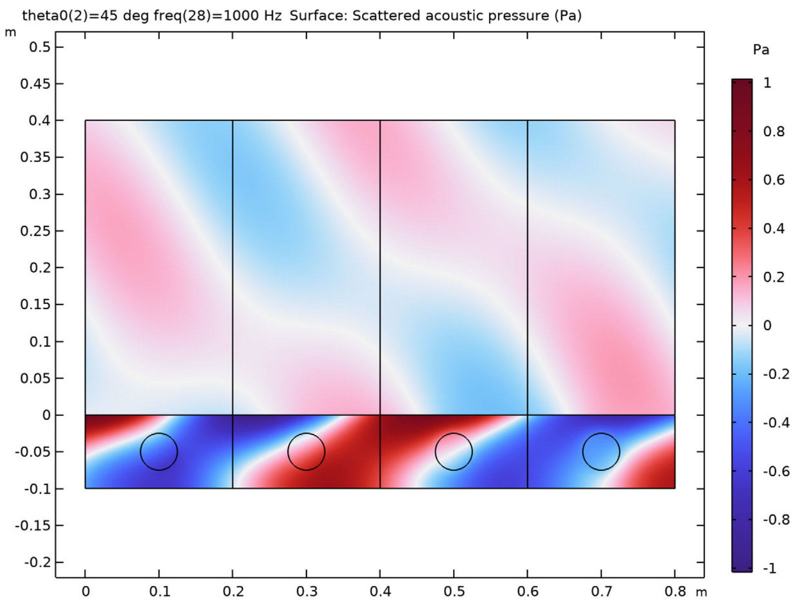
Compare the resulting plot with that in Figure 2.

Now change the frequency from 10 kHz to 1 kHz.

5 From the **Parameter value (freq (Hz))** list, choose **1000**.

6 In the **Scattered Acoustic Pressure** toolbar, click **Plot**.

The result should look like that in the figure below.



Total Acoustic Pressure

Next, plot the incident acoustic pressure field at 10 kHz for an incidence angle of 0^o

1 In the **Model Builder** window, right-click **Total Acoustic Pressure** and choose **Duplicate**.

Incident Acoustic Pressure

1 In the **Model Builder** window, under **Results** click **Total Acoustic Pressure 1**.

2 In the **Settings** window for **2D Plot Group**, type `Incident Acoustic Pressure` in the **Label** text field.

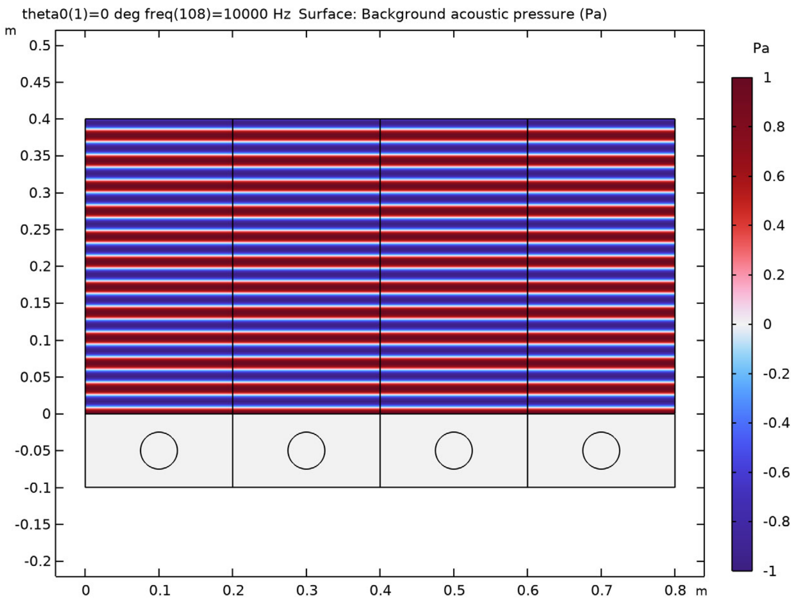
Surface 1

1 In the **Model Builder** window, expand the **Incident Acoustic Pressure** node, then click **Surface 1**.

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

3 In the **Expression** text field, type `acpr.p_b`.

4 In the **Incident Acoustic Pressure** toolbar, click **Plot**.



Next, create 1D plots to depict the absorption properties of the melamine absorber.

First, reproduce the plot in Figure 4, which shows the acoustic pressure at the surface of the porous melamine layer.

Point Pressure

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

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

3 Locate the **Data** section. From the **Dataset** list, choose **Study 1/ Parametric Solutions 1 (sol2)**.

4 Click to expand the **Title** section. From the **Title type** list, choose **Label**.

Point Graph 1

1 Right-click **Point Pressure** and choose **Point Graph**.

2 Select Point 2 only.

3 In the **Settings** window for **Point Graph**, click to expand the **Legends** section.

4 Select the **Show legends** check box.

5 In the **Point Pressure** toolbar, click **Plot**.

6 Click the **x-Axis Log Scale** button in the **Graphics** toolbar.

Proceed by plotting the acoustic normal impedance at the surface of the porous melamine layer. The plot should look like that in Figure 5.

Normal Impedance

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

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

3 Locate the **Data** section. From the **Dataset** list, choose **Study 1/ Parametric Solutions 1 (sol2)**.

4 Locate the **Title** section. From the **Title type** list, choose **Label**.

5 Locate the **Plot Settings** section.

6 Select the **x-axis label** check box. In the associated text field, type `f (Hz)`.

7 Select the **y-axis label** check box. In the associated text field, type `Z/(rho*c) (1)`.

8 Locate the **Legend** section. From the **Position** list, choose **Lower left**.

Global 1

1 Right-click **Normal Impedance** and choose **Global**.

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

3 In the table, enter the following settings:

Expression	Unit	Description
`Z`	`1`	`Specific surface normal impedance`
`Z_ana`	`1`	`Specific surface normal impedance (analytical)`

4 Click to expand the **Legends** section. In the **Normal Impedance** toolbar, click **Plot**.

5 Click the **x-Axis Log Scale** button in the **Graphics** toolbar.

Plot the absorption coefficient of the porous melamine layer for the two studied incidence angles (Figure 6).

Absorption Coefficient

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

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

3 Locate the **Data** section. From the **Dataset** list, choose **Study 1/ Parametric Solutions 1 (sol2)**.

4 Locate the **Title** section. From the **Title type** list, choose **Label**.

5 Locate the **Plot Settings** section.

6 Select the **x-axis label** check box. In the associated text field, type `f (Hz)`.

7 Select the **y-axis label** check box. In the associated text field, type `\alpha (1)`.

8 Locate the **Legend** section. From the **Position** list, choose **Lower right**.

Global 1

1 Right-click **Absorption Coefficient** and choose **Global**.

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

3 In the table, enter the following settings:

Expression	Unit	Description
alpha	1	Absorption coefficient
alpha_R	1	Absorption coefficient (based on R)
alpha_ana	1	Absorption coefficient (analytical)

4 In the **Absorption Coefficient** toolbar, click **Plot**.

5 Click the **x-Axis Log Scale** button in the **Graphics** toolbar.

Finally, plot the absorption coefficient of the porous melamine layer for normal incidence in octave and 1/3 octave bands (Figure 7).

Normal Incidence Absorption

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

2 In the **Settings** window for **1D Plot Group**, type `Normal Incidence Absorption` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Study 1/ Parametric Solutions 1 (sol2)**.

4 From the **Parameter selection (theta0)** list, choose **From list**.

5 In the **Parameter values (theta0 (deg))** list, select **0**.

6 Click to expand the **Title** section. From the **Title type** list, choose **Label**.

7 Locate the **Plot Settings** section.

8 Select the **x-axis label** check box. In the associated text field, type `f (Hz)`.

9 Select the **y-axis label** check box. In the associated text field, type `\alpha (1)`.

10 Locate the **Axis** section. Select the **x-axis log scale** check box.

11 Locate the **Legend** section. Clear the **Show legends** check box.

Octave Band 1

1 In the **Normal Incidence Absorption** toolbar, click **More Plots** and choose **Octave Band**.

2 In the **Settings** window for **Octave Band**, locate the **Selection** section.

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

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

5 From the **Expression type** list, choose **General (non-dB)**.

6 Locate the **Plot** section. From the **Quantity** list, choose **Band average power spectral density**.

7 Right-click **Octave Band 1** and choose **Duplicate**.

Octave Band 2

1 In the **Model Builder** window, click **Octave Band 2**.

2 In the **Settings** window for **Octave Band**, locate the **Plot** section.

3 From the **Band type** list, choose **1/3 octave**.

4 Right-click **Octave Band 2** and choose **Duplicate**.

Octave Band 3

1 In the **Model Builder** window, click **Octave Band 3**.

2 In the **Settings** window for **Octave Band**, locate the **Plot** section.

3 From the **Quantity** list, choose **Continuous power spectral density**.

4 Click to expand the **Coloring and Style** section. From the **Width** list, choose **2**.

5 In the **Normal Incidence Absorption** toolbar, click **Plot**.