



Model created in COMSOL Multiphysics 6.4

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 a solid inclusion. Inclusions are used in periodic configurations to improve absorption, in this model it is not optimized in any way. An analytical solution exists in the case where the layer is uniform. The model uses a 2D geometry of such a system and the **Periodic Port** to model the incident and reflected waves.

Model Definition

[Figure 1](#) depicts the geometry of the modeled system, in which an incident sound field hits the solid-backed porous melamine-foam layer at angle θ_0 . A solid inclusion, circular domain of radius a , is present in the porous layer. The thickness of the porous melamine layer is $H_p = 10$ cm and the height of the modeled air region is $H = 30$ cm. 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 (**Periodic Condition**) on the left and right boundaries to extend the domain to infinity. The incident field is modeled using the **Periodic Port** boundary condition. The port defines an incident plane wave at the given angle of incidence. The **Periodic Port** and **Diffraction Order Port** subfeatures combine to give a perfect non-reflecting condition for the outgoing waves.

Model the melamine foam using the Pressure Acoustics interface's **Poroacoustics** domain feature using the Johnson–Champoux–Allard (JCA) model with a rigid frame. This is an equivalent fluid model for a rigid framed 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

TABLE I: MELAMINE FOAM MATERIAL PARAMETERS.

Symbol	Value	Description
L_{th}	470 μm	Thermal characteristic length
L_v	240 μm	Viscous characteristic length
τ	1.0059	Tortuosity factor

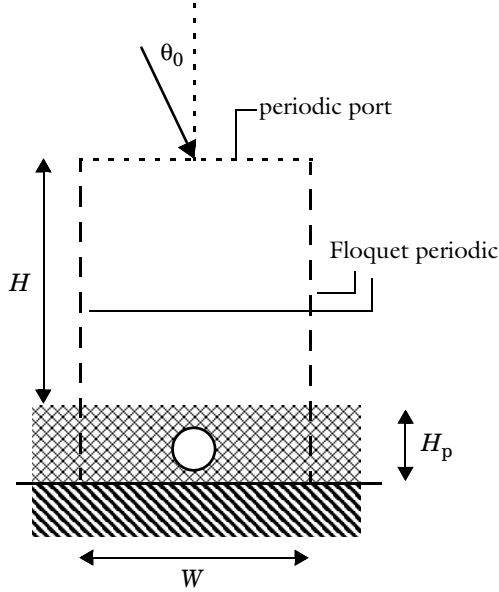


Figure 1: Geometry of the modeled system, the air inclusion has a radius a .

The incident background pressure field is given as

$$p_{inc} = e^{-i(\mathbf{k} \cdot \mathbf{x})} \quad \mathbf{k} = k_0(\sin\theta_0, -\cos\theta_0) \quad (1)$$

where θ_0 is the incidence angle and k_0 is the wave number in the free field (air domain). The field is automatically defined by the **Periodic Port** and the associated wave vector \mathbf{k} is picked up by the **Periodic Condition**.

Two parameters that characterize the absorption properties of the porous absorber are the specific normal 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

$$\alpha = 1 - |R|^2 \quad R = \frac{P_{\text{scat}}}{P_{\text{inc}}} \quad (2)$$

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. The **Periodic Port** defines variables exist for the scattered (outgoing) pressure `acpr.pport1.p_out` and the incident pressure `acpr.pport1.p_in`. These represent the plane wave components.

In general the absorption coefficient can be defined through its energetic definitions as

$$\alpha = 1 - \frac{P_{\text{scat}}}{P_{\text{inc}}} \quad (3)$$

where P_{scat} is the total scattered power and P_{inc} is the total incident power. Both of these quantities are defined by the periodic port. The incident power is `acpr.pport1.P_in` and the total scattered power is `acpr.pport1.P_out_tot`. The total power variable is the sum of the scattered plane wave power and all diffraction orders included in the model.

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

$$Z = \frac{1}{\rho c} \frac{p}{u_n} \quad (4)$$

where ρ is the density of air, c is the speed of sound, and $u_n = \mathbf{u} \cdot \mathbf{n}$ 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

$$\begin{aligned}
Z_{\text{ana}} &= \frac{1}{\rho c} \frac{-iZ_c k_c}{k_x} \cot(k_x H_p) \\
k_x &= \sqrt{k_c^2 - k_y^2} \\
k_y &= k_0 \sin(\theta_0)
\end{aligned} \tag{5}$$

where a subscript “c” represents complex-valued specific characteristic impedance and wave number variables from the **Poroacoustic** domain. From the normal impedance the analytical expression for the absorption coefficient is deduced.

DIFFRACTION ORDER PORTS

By itself the **Periodic Port** only works as a plane wave reflection condition (specular reflections). To capture the total acoustic field add the necessary **Diffraction Order Port** subfeatures. To assess how many are needed analyze the model at the highest frequency and evaluate the imaginary part of the mode wave numbers. This is done in the **Evaluation Group** in the model. Make sure to include enough modes such that all modes have a non-zero imaginary part. This means that the last included diffraction order mode is non-propagating. Note that diffraction order mode $m = 0$ is the specular reflection, and it is already handled by the main **Periodic Port** feature.

Results and Discussion

Figure 2 and Figure 3 plot the acoustic pressure fields at the frequency $f = 10$ kHz and incidence angles of 0° and 45° respectively. Notice how the wave is absorbed in the porous layer. Figure 4 shows the sound pressure level (SPL) for the last case.

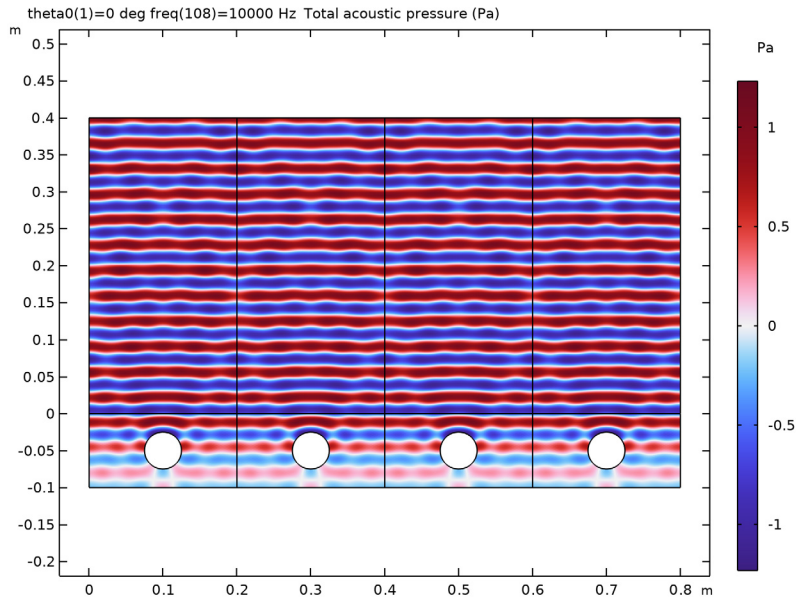


Figure 2: Acoustic pressure field for an incidence angle of 0° and frequency $f = 10$ kHz.

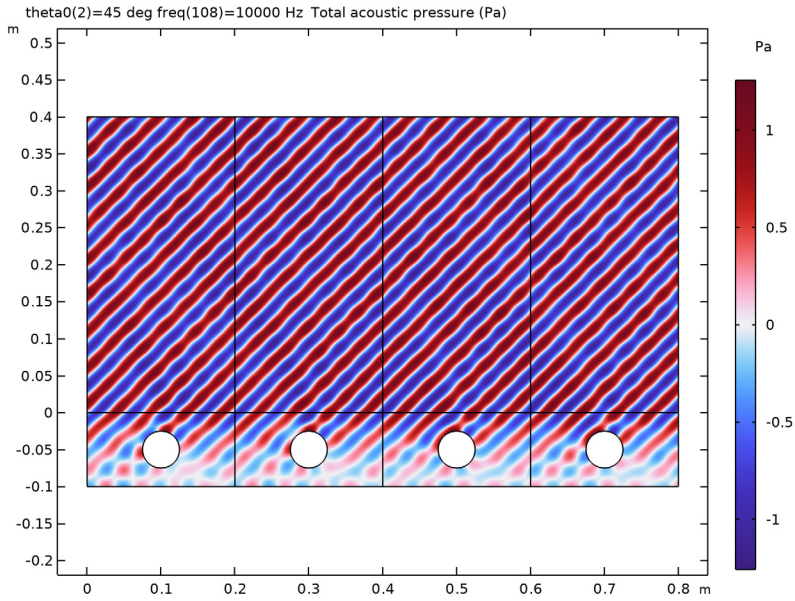


Figure 3: Acoustic pressure for an incidence angle of 0° and frequency $f = 10$ kHz.

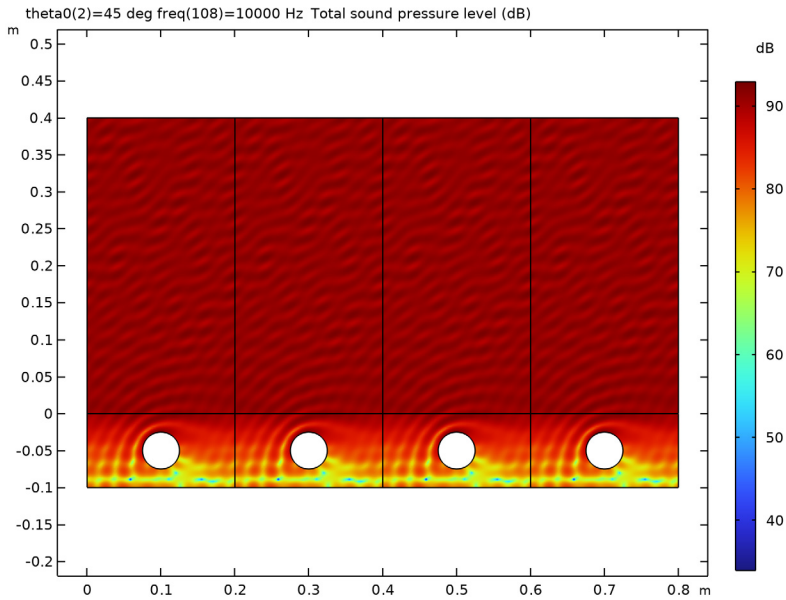


Figure 4: Sound pressure level for an incidence angle of 0° and frequency $f = 10$ kHz.

Figure 5 depicts the acoustic pressure (the real part) at the surface of the porous melamine layer for two angles of incidence. Figure 6 plots the specific acoustic impedance at the surface of the porous absorber (computed as the average across the surface). Figure 7 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 8 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 7, 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.

Finally, Figure 9 shows the power associated with the different diffraction order modes for the two angles of incidence. Notice the cutoff frequency for the different modes. It is also interesting to see that for the current configuration the power in the diffraction orders is comparable to the power associated with the plane-wave component.

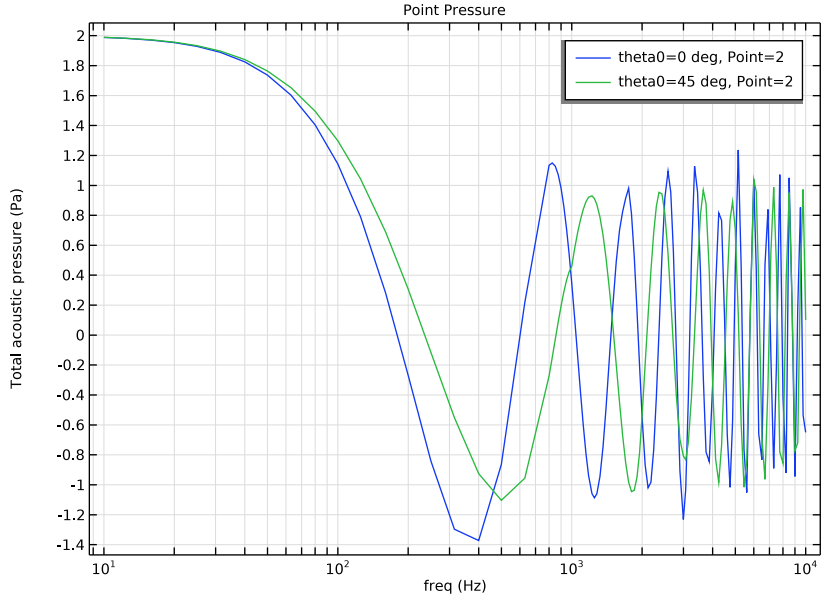


Figure 5: Sound pressure level at the surface of the porous absorber.

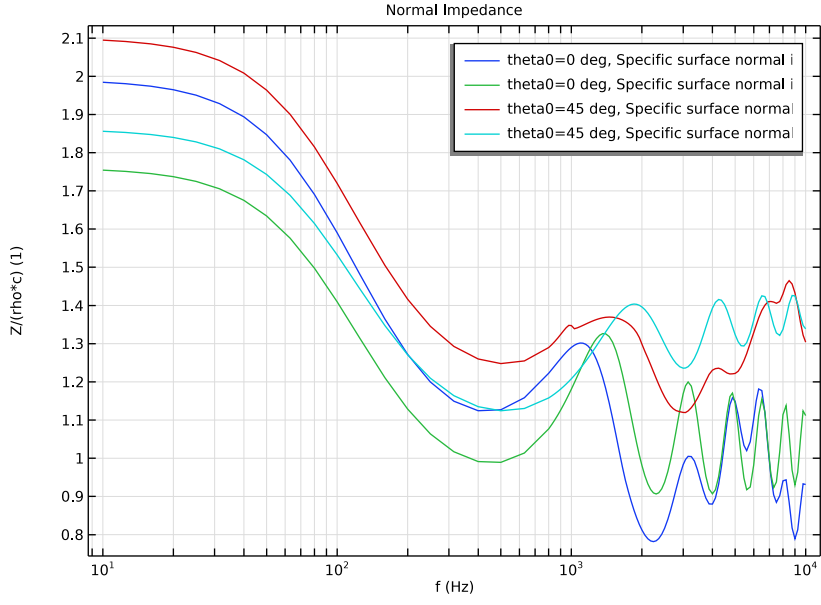


Figure 6: Specific acoustic impedance at the surface of the porous absorber.

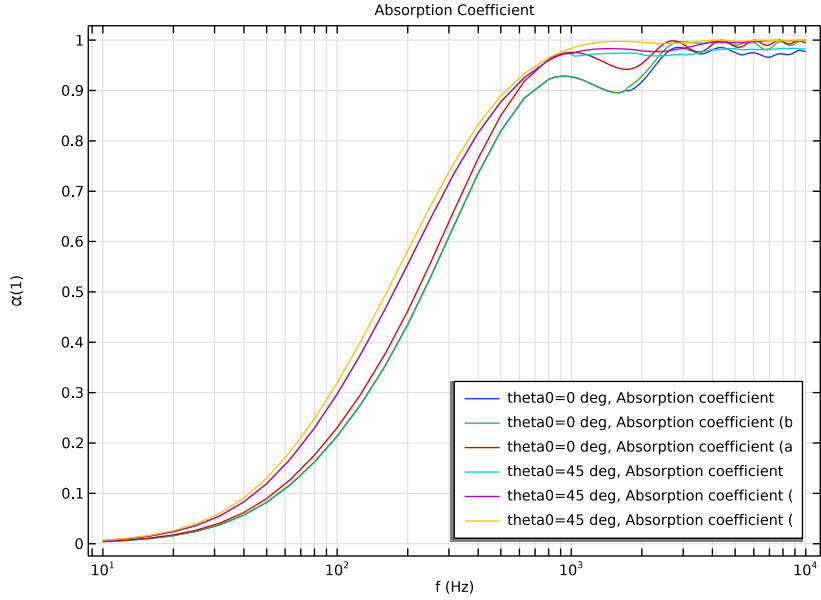


Figure 7: Absorption coefficient for the porous melamine absorber as function of frequency and incidence angle. Compared to the reflection coefficient based expression and the analytical solution of a uniform layer.

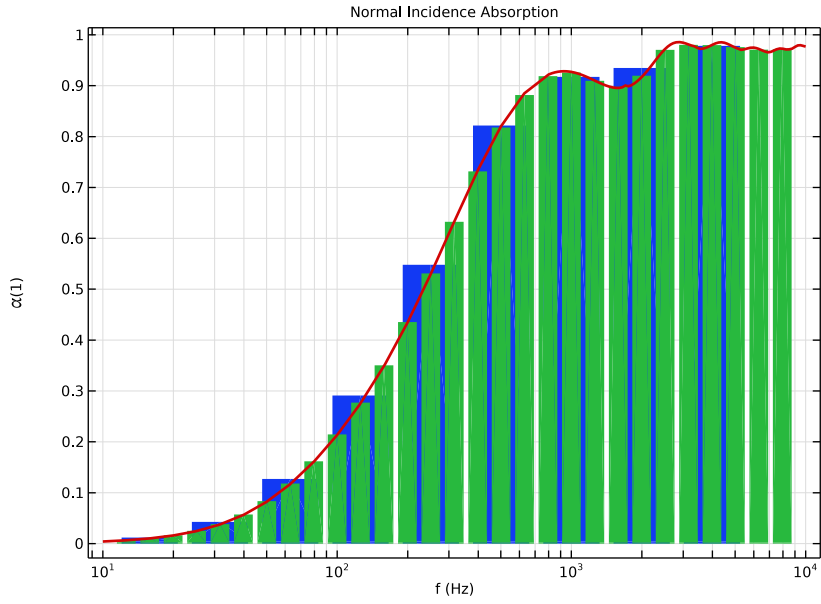


Figure 8: Absorption coefficient of the porous melamine absorber for normal incidence in octave bands, 1/3 octave bands, and continuous frequency.

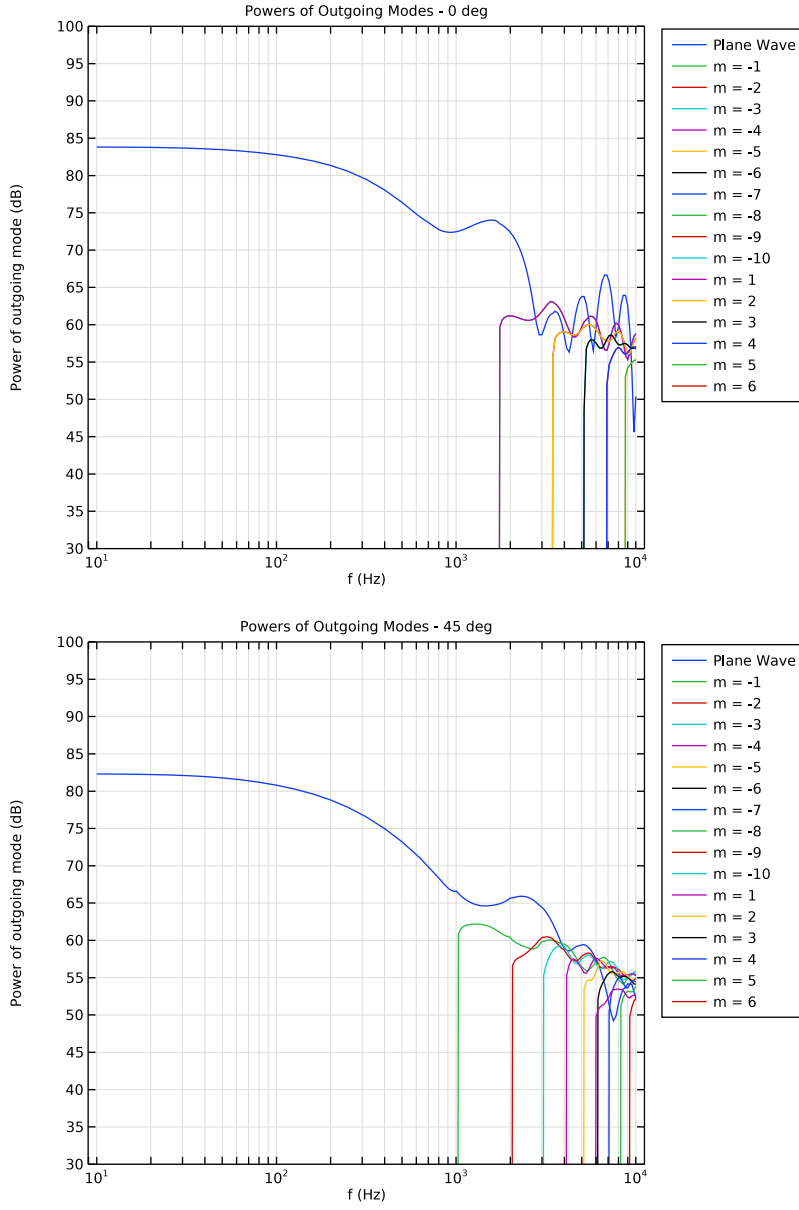


Figure 9: Power (in dB) associated with the different diffraction order modes for the two angles of incidence.

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

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

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+Hp.
- 5 Locate the **Position** section. In the **y** text field, type 0.
- 6 In the **y** text field, type -Hp.




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


Layer name	Thickness (m)
Layer 1	Hp

Circle 1 (c1)

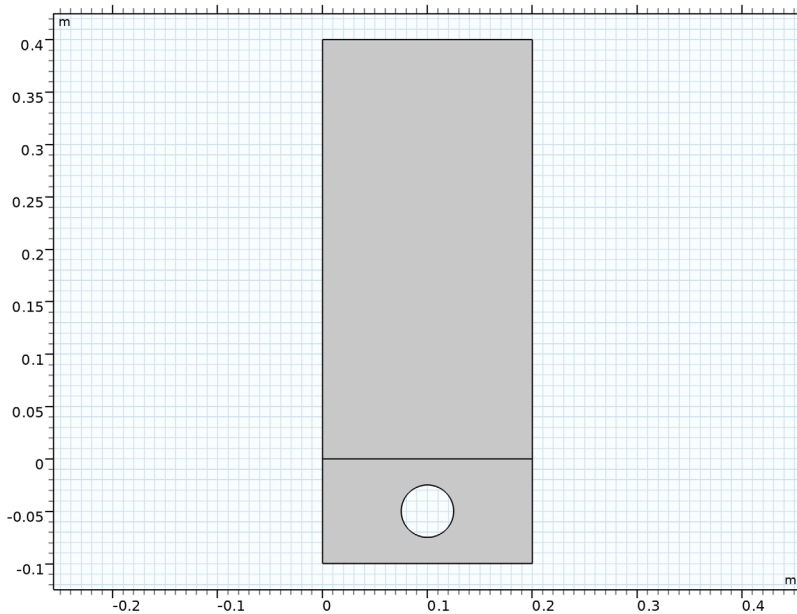
- 1 In the **Geometry** toolbar, click  **Circle**.
- 2 In the **Settings** window for **Circle**, locate the **Size and Shape** section.
- 3 In the **Radius** text field, type a.
- 4 Locate the **Position** section. In the **x** text field, type $W/2$.
- 5 In the **y** text field, type $-Hp/2$.

Difference 1 (dif1)

- 1 In the **Geometry** toolbar, click  **Booleans and Partitions** and choose **Difference**.
- 2 Select the object **r1** only.
- 3 In the **Settings** window for **Difference**, locate the **Difference** section.
- 4 Click to select the  **Activate Selection** toggle button for **Objects to subtract**.
- 5 Select the object **c1** only.
- 6 Click  **Build All Objects**.

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 - Z and alpha

- 1 In the **Definitions** toolbar, click  **Local Variables**.
- 2 In the **Settings** window for **Variables**, type Variables 1 - Z and alpha in the **Label** text field.
- 3 Locate the **Variables** section. 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 uniform layer with a sound hard backing, see [Equation 5](#).


Variables 2 - Analytical

- 1 In the **Definitions** toolbar, click  **Local Variables**.


- 2 In the **Settings** window for **Variables**, type Variables 2 - Analytical in the **Label** text field.
- 3 Locate the **Variables** section. 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 periodic port and one on the porous-air interface. They will 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 5 only.



Average 2 (aveop2)

- 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.


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 **Materials** 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 the **Add to Component** button in the window toolbar.
- 5 In the **Materials** 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	l	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	Rf0	Pa·s/m ²	Poroacoustics model
Thermal characteristic length	Lth	Lth0	m	Poroacoustics model
Viscous characteristic length	Lv	Lv0	m	Poroacoustics model
Tortuosity factor	tau	tau0	l	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.

PRESSURE ACOUSTICS, FREQUENCY DOMAIN (ACPR)

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)**.

Periodic Condition 1

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Periodic Condition**.
- 2 Select Boundaries 1, 3, 6, and 7 only.
- 3 In the **Settings** window for **Periodic Condition**, locate the **Periodicity Settings** section.
- 4 From the **Type of periodicity** list, choose **Floquet periodicity**.

Come back and select the k-vector from the **Periodic Port** after defining it.


Periodic Port 1

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Periodic Port**.
- 2 Select Boundary 5 only.
- 3 In the **Settings** window for **Periodic Port**, locate the **Port Mode Settings** section.
- 4 In the A_p^{in} text field, type 1.

5 In the θ_{in} text field, type θ_0 .

Proceed and add the necessary number of **Diffraction Order Port** subfeatures. In this model the diffraction orders m from -10 to 6 are needed. This is discussed in the model documentation.


Diffraction Order Port 1

- 1 In the **Physics** toolbar, click  **Attributes** and choose **Diffraction Order Port**.
- 2 In the **Settings** window for **Diffraction Order Port**, locate the **Diffraction Order Port** section.
- 3 In the m text field, type -1.

Periodic Port 1

In the **Model Builder** window, click **Periodic Port 1**.

Diffraction Order Port 2

- 1 In the **Physics** toolbar, click  **Attributes** and choose **Diffraction Order Port**.
- 2 In the **Settings** window for **Diffraction Order Port**, locate the **Diffraction Order Port** section.
- 3 In the m text field, type -2.

Repeat this step for the remaining diffraction orders m , such that all from -10 to 6 are included.



Now all the necessary diffraction orders are included to get the full expansion at the periodic port. Make the final setting on the periodic condition.

Periodic Condition 1


- 1 In the **Model Builder** window, under **Component 1 (comp1) > Pressure Acoustics, Frequency Domain (acpr)** click **Periodic Condition 1**.
- 2 In the **Settings** window for **Periodic Condition**, locate the **Periodicity Settings** section.
- 3 From the k_F list, choose **Periodic port Floquet wave number vector (acpr/pport1)**.

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 6 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 Domain 1 only.

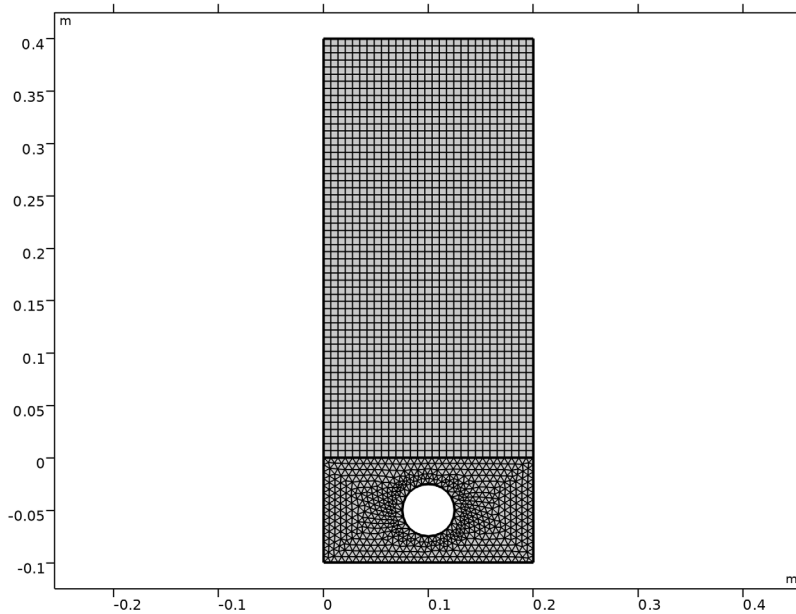
Size

- 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 λ_{\min} with 5 elements.



Mapped 1

- 1 In the **Mesh** toolbar, click  **Mapped**.
- 2 In the **Settings** window for **Mapped**, click  **Build All**.
- 3 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, 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, 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 θ_0 for the values 0° and 45° .

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
θ_0 (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.

RESULTS



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** checkbox.
- 6 Find the **Wave vector** subsection. In the **X** text field, type kx .
- 7 In the **Y** text field, type ky .


Acoustic Pressure


- 1 In the **Model Builder** window, under **Results** click **Acoustic Pressure (acpr)**.
- 2 In the **Settings** window for **2D Plot Group**, type Acoustic Pressure in the **Label** text field.
- 3 Locate the **Data** section. From the **Dataset** list, choose **Array 2D 1**.

Surface 1

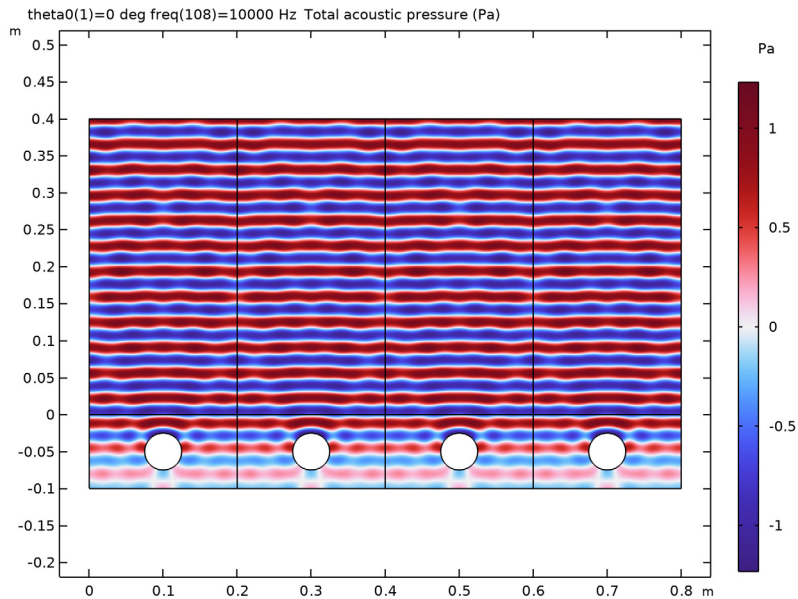
- 1 In the **Model Builder** window, expand the **Acoustic Pressure** node, then click **Surface 1**.
- 2 In the **Acoustic Pressure** toolbar, click  **Plot**.
- 3 Click the  **Zoom Extents** button in the **Graphics** toolbar.
Compare the resulting plot with that in [Figure 3](#).
Now change the incidence angle from 45° to 0° .

Acoustic Pressure

- 1 In the **Model Builder** window, click **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 **Acoustic Pressure** toolbar, click  **Plot**.

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

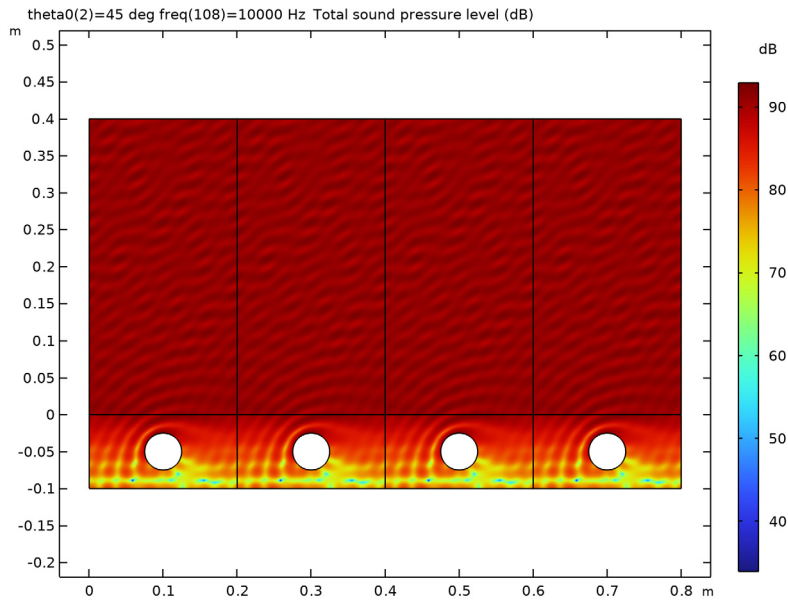
The result should look like that in the following figure.



Sound Pressure Level

- 1 In the **Model Builder** window, under **Results** click **Sound Pressure Level (acpr)**.
- 2 In the **Settings** window for **2D Plot Group**, type Sound Pressure Level1 in the **Label** text field.


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




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


First, reproduce the plot in [Figure 5](#), which shows the acoustic pressure at the surface of the porous melamine layer.

Point Pressure


- 1 In the **Results** toolbar, click  **ID Plot Group**.
- 2 In the **Settings** window for **ID 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** checkbox.
- 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 6](#).



Normal Impedance

- 1 In the **Results** toolbar, click  **ID Plot Group**.
- 2 In the **Settings** window for **ID 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** checkbox. In the associated text field, type f (Hz).
- 7 Select the **y-axis label** checkbox. In the associated text field, type $Z/(\rho \cdot c)$ (1).
- 8 Locate the **Legend** section. From the **Position** list, choose **Upper right**.

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 7](#)).

Absorption Coefficient



- 1 In the **Results** toolbar, click  **ID Plot Group**.
- 2 In the **Settings** window for **ID 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** checkbox. In the associated text field, type f (Hz).
- 7 Select the **y-axis label** checkbox. In the associated text field, type α (1).
- 8 Locate the **Legend** section. From the **Position** list, choose **Lower right**.

Global I


- 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.

Next, plot the absorption coefficient of the porous melamine layer for normal incidence in octave and 1/3 octave bands (Figure 8).

Normal Incidence Absorption

- 1 In the **Results** toolbar, click  **ID Plot Group**.
- 2 In the **Settings** window for **ID 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 box, 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** checkbox. In the associated text field, type f (Hz).
- 9 Select the **y-axis label** checkbox. In the associated text field, type α (1).
- 10 Locate the **Axis** section. Select the **x-axis log scale** checkbox.
- 11 Locate the **Legend** section. Clear the **Show legends** checkbox.


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 α .
- 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**.

Octave Band 2


- 1 Right-click **Octave Band 1** and choose **Duplicate**.
- 2 In the **Settings** window for **Octave Band**, locate the **Plot** section.
- 3 From the **Band type** list, choose **1/3 octave**.

Octave Band 3

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

The final two plots and evaluation group are used to assess how many diffraction order ports are needed for the given frequency range and angles of incidence.

Powers of Outgoing Modes - 0 deg

- 1 In the **Results** toolbar, click  **ID Plot Group**.
- 2 In the **Settings** window for **ID Plot Group**, type Powers of Outgoing Modes - 0 deg 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 **First**.
- 5 Click to expand the **Title** section. From the **Title type** list, choose **Label**.
- 6 Locate the **Plot Settings** section.
- 7 Select the **x-axis label** checkbox. In the associated text field, type f (Hz).

- 8 Select the **y-axis label** checkbox. In the associated text field, type Power of outgoing mode (dB).
- 9 Locate the **Axis** section. Select the **x-axis log scale** checkbox.
- 10 Locate the **Legend** section. From the **Layout** list, choose **Outside graph axis area**.

Global 1

- 1 Right-click **Powers of Outgoing Modes - 0 deg** 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
$10 \cdot \log_{10}(\text{acpr.pport1.P_out} / \text{acpr.Pref_SWL})$	dB	Plane Wave
$10 \cdot \log_{10}(\text{acpr.pport1.dport1.P_out} / \text{acpr.Pref_SWL})$	dB	m = -1
$10 \cdot \log_{10}(\text{acpr.pport1.dport2.P_out} / \text{acpr.Pref_SWL})$	dB	m = -2
$10 \cdot \log_{10}(\text{acpr.pport1.dport3.P_out} / \text{acpr.Pref_SWL})$	dB	m = -3
$10 \cdot \log_{10}(\text{acpr.pport1.dport4.P_out} / \text{acpr.Pref_SWL})$	dB	m = -4
$10 \cdot \log_{10}(\text{acpr.pport1.dport5.P_out} / \text{acpr.Pref_SWL})$	dB	m = -5
$10 \cdot \log_{10}(\text{acpr.pport1.dport6.P_out} / \text{acpr.Pref_SWL})$	dB	m = -6
$10 \cdot \log_{10}(\text{acpr.pport1.dport7.P_out} / \text{acpr.Pref_SWL})$	dB	m = -7
$10 \cdot \log_{10}(\text{acpr.pport1.dport8.P_out} / \text{acpr.Pref_SWL})$	dB	m = -8
$10 \cdot \log_{10}(\text{acpr.pport1.dport9.P_out} / \text{acpr.Pref_SWL})$	dB	m = -9
$10 \cdot \log_{10}(\text{acpr.pport1.dport10.P_out} / \text{acpr.Pref_SWL})$	dB	m = -10
$10 \cdot \log_{10}(\text{acpr.pport1.dport11.P_out} / \text{acpr.Pref_SWL})$	dB	m = 1
$10 \cdot \log_{10}(\text{acpr.pport1.dport12.P_out} / \text{acpr.Pref_SWL})$	dB	m = 2
$10 \cdot \log_{10}(\text{acpr.pport1.dport13.P_out} / \text{acpr.Pref_SWL})$	dB	m = 3
$10 \cdot \log_{10}(\text{acpr.pport1.dport14.P_out} / \text{acpr.Pref_SWL})$	dB	m = 4

Expression	Unit	Description
$10 \cdot \log_{10}(\text{acpr.pport1.dport15.P_out} / \text{acpr.Pref_SWL})$	dB	m = 5
$10 \cdot \log_{10}(\text{acpr.pport1.dport16.P_out} / \text{acpr.Pref_SWL})$	dB	m = 6

4 Click to expand the **Legends** section. Find the **Include** subsection. Clear the **Solution** checkbox.

5 In the **Powers of Outgoing Modes - 0 deg** toolbar, click  **Plot**.

Powers of Outgoing Modes - 0 deg

1 In the **Model Builder** window, click **Powers of Outgoing Modes - 0 deg**.

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

3 Select the **Manual axis limits** checkbox.

4 In the **y minimum** text field, type 30.

5 In the **y maximum** text field, type 100.

6 In the **Powers of Outgoing Modes - 0 deg** toolbar, click  **Plot**.

This plot shows the power in the different diffraction order modes at 0 deg. incidence. At frequencies above 2000 Hz several modes become important, comparable to the plane wave mode.

Powers of Outgoing Modes - 45 deg

1 Right-click **Powers of Outgoing Modes - 0 deg** and choose **Duplicate**.


2 In the **Settings** window for **ID Plot Group**, type Powers of Outgoing Modes - 45 deg in the **Label** text field.

3 Locate the **Data** section. From the **Parameter selection (theta0)** list, choose **Last**.

4 In the **Powers of Outgoing Modes - 45 deg** toolbar, click  **Plot**.

This plot shows the power in the different diffraction order modes at 45 deg. incidence. At frequencies above 1000 Hz several modes become important, comparable to the plane wave mode.

Evaluation Group 1 - Diffraction Order

1 In the **Results** toolbar, click  **Evaluation Group**.

2 In the **Settings** window for **Evaluation Group**, type Evaluation Group 1 - Diffraction Order 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 (freq)** list, choose **Last**.
- 5 Locate the **Transformation** section. Select the **Transpose** checkbox.
- 6 Click to expand the **Format** section. From the **Include parameters** list, choose **On**.

Global Evaluation I

- 1 Right-click **Evaluation Group I - Diffraction Order** and choose **Global Evaluation**.
- 2 In the **Settings** window for **Global Evaluation**, locate the **Expressions** section.
- 3 In the table, enter the following settings:

Expression	Unit	Description
$\text{imag}(\text{acpr.pport1.dport1.kn})$	rad/m	$m = -1$
$\text{imag}(\text{acpr.pport1.dport2.kn})$	rad/m	$m = -2$
$\text{imag}(\text{acpr.pport1.dport3.kn})$	rad/m	$m = -3$
$\text{imag}(\text{acpr.pport1.dport4.kn})$	rad/m	$m = -4$
$\text{imag}(\text{acpr.pport1.dport5.kn})$	rad/m	$m = -5$
$\text{imag}(\text{acpr.pport1.dport6.kn})$	rad/m	$m = -6$
$\text{imag}(\text{acpr.pport1.dport7.kn})$	rad/m	$m = -7$
$\text{imag}(\text{acpr.pport1.dport8.kn})$	rad/m	$m = -8$
$\text{imag}(\text{acpr.pport1.dport9.kn})$	rad/m	$m = -9$
$\text{imag}(\text{acpr.pport1.dport10.kn})$	rad/m	$m = -10$
$\text{imag}(\text{acpr.pport1.dport11.kn})$	rad/m	$m = 1$
$\text{imag}(\text{acpr.pport1.dport12.kn})$	rad/m	$m = 2$
$\text{imag}(\text{acpr.pport1.dport13.kn})$	rad/m	$m = 3$
$\text{imag}(\text{acpr.pport1.dport14.kn})$	rad/m	$m = 4$
$\text{imag}(\text{acpr.pport1.dport15.kn})$	rad/m	$m = 5$
$\text{imag}(\text{acpr.pport1.dport16.kn})$	rad/m	$m = 6$

- 4 In the **Evaluation Group I - Diffraction Order** toolbar, click  **Evaluate**.

This evaluation performed at the highest study frequency can be used to see when enough diffraction order ports have been added. As soon as the imaginary part of the port wave number is no longer 0, it becomes non-propagating. This happens, for the two angles if incidence combined, at $m = -10$ and $m = 6$. This analysis depends on the angle of incidence and should be done at the highest frequency.