Schroeder Diffuser in 2D

Introduction

Sound diffusers are objects or surfaces that are designed to reflect incident sound energy evenly across angles. They are widely used in room acoustics as a way to influence the spatial distribution of the sound field without necessarily attenuating it. One common type of diffuser is the Schroeder diffuser, also called well-based diffuser, which consists of a series of wells of different depths. The depths are determined from a mathematical sequence, such as quadratic residue or primitive root. The principle behind this type of diffuser is that each well will re-emit the incident wave with a different phase shift, causing interferences between the waves emitted by the different wells. The mathematical sequence used to determine the depths of the wells will then dictate the interference pattern and, hence, the polar response of the diffuser.

This model demonstrates how to calculate the scattering coefficient with the *Pressure Acoustics, Frequency Domain* interface. This coefficient is one of the main inputs for expressing boundary conditions in typical room acoustic simulations. Its measurement procedure can be complicated to set up. Therefore. it is more efficient to determine the data numerically. In addition, the effect of periodicity is investigated by studying the responses from different arrangements of the same diffuser.

Model Definition

The model represents a primitive root diffuser, a type of Schroeder diffuser which aims at eliminating the specular component in the reflected energy polar response (see Ref. 1). The model at hand is based on the primitive root sequence with 7 as odd prime, resulting in a diffuser with 6 wells. The study is carried out in 2D in order to considerably reduce the number of degrees of freedom in the simulation. Three cases are taken into account as shown in Figure 1:

- Asingle diffuser flushed in an infinite baffle
- An arrangement of 5 diffusers adjacent to each other flushed in an infinite baffle
- An infinite arrangement of diffusers (a single unit cell is shown)

In the first two cases, a semicircle with radius $r_0 = 10\ \mathrm{m}$ is added to act as an integration line in the far field. The diffusers are surrounded by an air domain terminated by a **Perfectly Matched Boundary**, and the sound field outside of the calculation domain is obtained from **Exterior Field Calculation**. In the case of the infinite arrangement, **Periodic Condition>Floquet periodicity** is used to virtually extend the domain in both directions along the x-axis.

A plane wave with incidence angle θ_0 from the y-axis is defined as incoming on the diffuser arrangements. When present, the specular reflection from the infinite baffle is also included in the **Background Pressure Field**; this allows the solver to only compute the effect of the diffuser relative to the ideal sound field from a single infinite baffle. The incidence angle is varied in an **Auxiliary Sweep** from $\theta_0 = -80°$ to $\theta_0 = 80°$ with an increment of 10°, resulting in 17 incidence angles. Octave bands from 125 Hz to 4000 Hz are taken into account with 6 frequencies per band by setting up a **Parametric Sweep** on the band number parameter n.

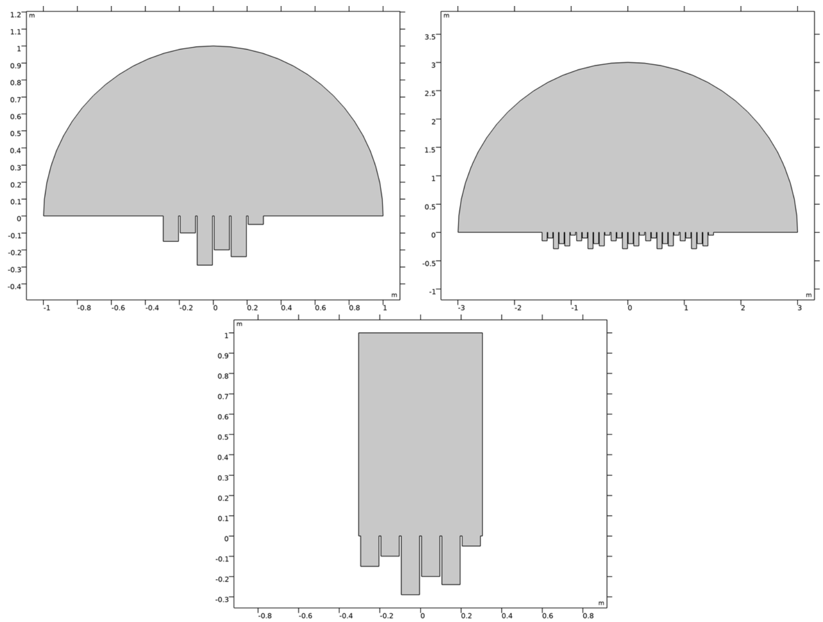


Figure 1: Geometries of the diffuser arrangements. Top left: single diffuser; Top right: 5-unit arrangement; Bottom: infinite arrangement.

SCATTERING COEFFICIENT

The scattering coefficient s is defined as the power ratio (see Ref. 1)

$$s = 1 - \frac{P_{\mathrm{spec}}}{P_{\mathrm{tot}}} \tag{1}$$

with P_{spec} the power reflected in the specular direction and P_{tot} the total reflected power. In this model, power is calculated by evaluating sound intensity on a semicircle Ω with radius r_0 located in the far field. After defining the reflected sound pressure p_r, the total power is obtained from the line integral (see Ref. 2, 3)

$$P_{tot} = \frac{1}{\rho c}\int_{\Omega}|p_r|^2 dl \tag{2}$$

This quantity can be evaluated directly with **Component 1>Definitions>Nonlocal Couplings> Integration**. For the specular power, sound intensity is integrated over a fraction of the semicircle centered around the specular direction θ_s. With ε an angular increment, the integration arc is defined as $\Gamma:\ \theta \in [\theta_s - \varepsilon, \theta_s + \varepsilon]$. This leads to

$$P_{spec} = \frac{1}{\rho c}\int_{\Gamma}|p_r|^2 dl \tag{3}$$

$$P_{spec} = \frac{1}{\rho c}\int_{\theta_s - \varepsilon}^{\theta_s + \varepsilon}|p_r(\theta)|^2 r_0 d\theta \tag{4}$$

When ε tends to zero, the integral becomes

$$P_{spec} = \frac{1}{\rho c}\int_{-\pi/2}^{\pi/2}|p_r(\theta)|^2 \delta(\theta - \theta_s) r_0 d\theta \tag{5}$$

With δ the delta function. From convolving the absolute squared pressure with the delta function, it follows that the power reflected in the specular direction can be evaluated as

$$P_{spec} = \frac{r_0}{\rho c}|p_r(\theta_s)|^2 \tag{6}$$

Recalling Equation 1, the scattering coefficient can then be expressed as

$$s = 1 - \frac{r_0|p_r(\theta_s)|^2}{\int_{\Omega}|p_r|^2 dl} \tag{7}$$

For the infinite arrangement, it is not possible to define a semicircle that would encompass the whole geometry. The scattering coefficient is therefore based on its intensity definition

$$s = 1 - \frac{I_{spec}}{I_{tot}} \tag{8}$$

with I_{spec} the reflected intensity magnitude in the specular direction and I_{tot} the total reflected intensity magnitude. The reflected intensity $\mathbf{I}_r$ can be obtained in the model by checking the box **Pressure Acoustics, Frequency Domain>Background Pressure Field>Calculate background and scattered field intensity**. The specular magnitude can then be calculated by taking the dot product with the specular direction unit vector $\mathbf{e}_s$, and the total magnitude is a straightforward calculation. However, since the geometry is infinite, every point on the x-axis is a valid option as the origin for the unit vector. Therefore, the values are integrated over the top boundary L of the domain to give the scattering coefficient

$$s = 1 - \frac{\int_L (\mathbf{I}_r \cdot \mathbf{e}_s) dl}{\int_L \|\mathbf{I}_r\| dl} \tag{9}$$

The coefficient in Equation 7 or Equation 9 gives a value for each incidence angle and frequency included in the study. To obtain the random incidence scattering coefficient in octave bands, the quantity calculated is averaged over angles and frequencies per band in **Evaluation Group>Global Evaluation** by selecting **Data>Table columns>Outer solutions** and **Data series operation>Transformation>Average**.

Results and Discussion

The sound pressure scattered by the diffuser arrangements and their infinite baffles is shown in Figure 2 for $\theta_0 = 0°$ and $f = 1335$ Hz. In this case, the plane waves propagating in the wells of the Schroeder diffuser are clearly visible. Moreover, it is seen that the planar wavefront that would result from a perfectly specular reflection is disrupted by the presence of the wells. This is especially true in front of the diffuser arrangements, where the wavefront tends to a cylindrical wave. It also appears that destructive interferences create directions with greatly reduced energy. Although this effect is present in the single diffuser, it is seen to be more prominent in the 5-unit arrangement.

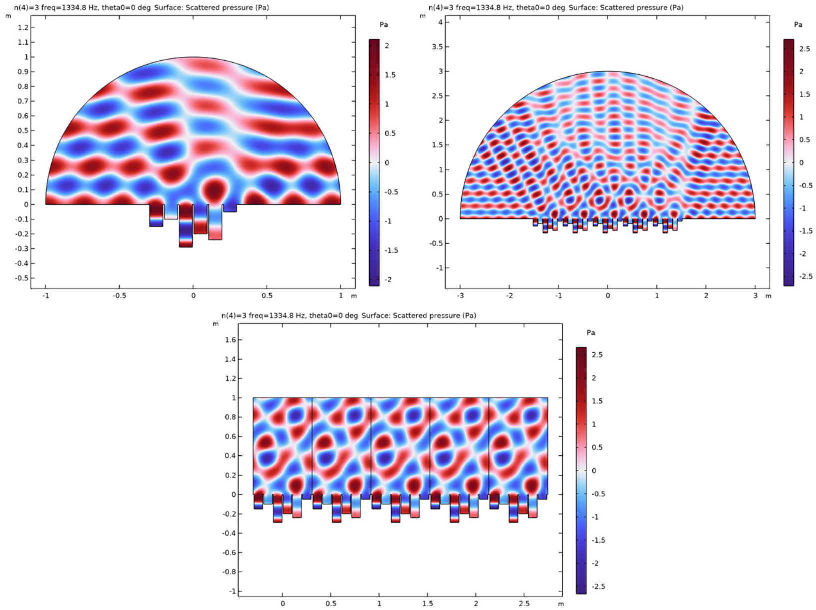


Figure 2: Scattered pressure for $\theta_0 = 0°$ *and* $f = 1335$ Hz. *Top left: single diffuser; Top right: 5-unit arrangement; Bottom: infinite arrangement.*

Further investigation of the scattered sound field can be made from the SPL polar responses of the single diffuser in Figure 3 and the 5-unit arrangement in Figure 4. They are evaluated in the far field at a distance r_0 = 10 m, for θ_0 = 30° and the six frequencies composing the 250 Hz octave band in this study. This type of plot could not be generated for the infinite arrangement as it requires to evaluate sound pressure on a surrounding semicircle. It can be observed that the primitive root diffuser does reduce the energy reflected in the specular direction as intended. The difference between the SPL in the specular direction and the maximum SPL lies between 1 dB and 4 dB for the single diffuser, with energy being distributed rather evenly across angles. For the 5-unit arrangement, the SPL difference goes from 4 dB to 9 dB between the specular and maximum directions. However, it is seen that the reflected energy is concentrated between 15° and 45°, as the lobes exhibit large amplitudes for both peaks and dips in that region of the polar response. This confirms the idea that a periodic arrangement reinforces certain reflection and attenuation directions for a given diffuser.

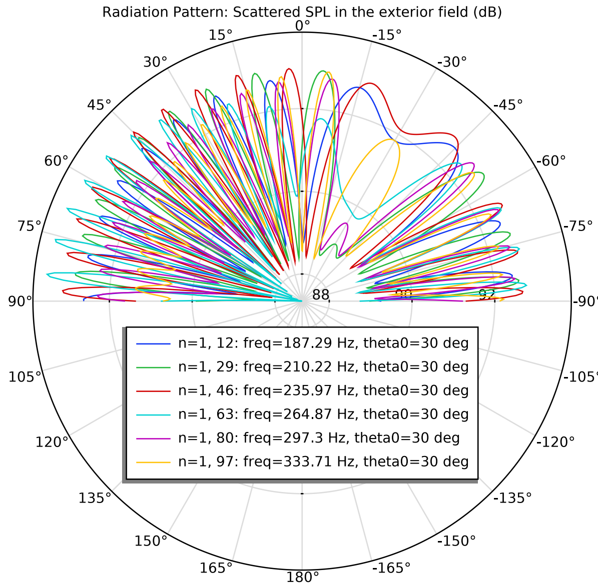


Figure 3: Polar response of the single diffuser for θ_0 *= 30° in the 250 Hz octave band.*

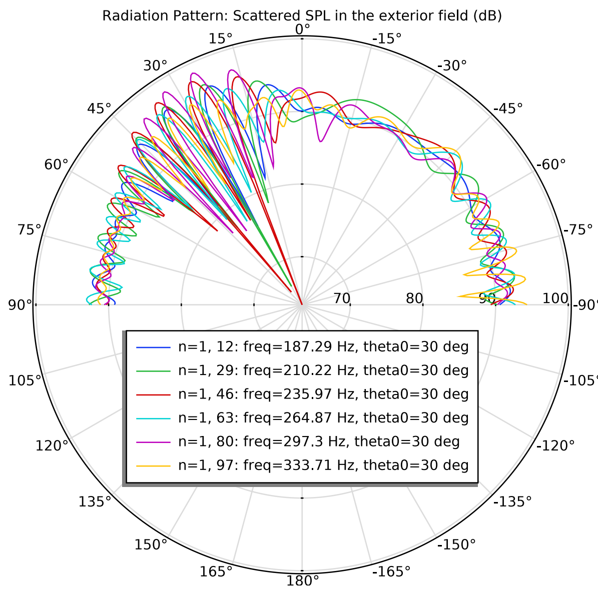


Figure 4: Polar response of the 5-unit arrangement for θ_0 *= 30° in the 250 Hz octave band.*

The scattering coefficients of the three diffuser arrangements is shown in Figure 5. Despite the differences observed in their polar responses, it is seen that the single diffuser and the 5-unit arrangement return similar values for all frequencies. This illustrates one of the shortcomings of the scattering coefficient: it only quantifies nonspecularly reflected energy without any consideration of the energy distribution over angles. Two diffusers could therefore have the same scattering coefficient and yet behave very differently. Nevertheless, this coefficient still provides valuable information in a simple manner. The infinite arrangement also gives interesting results. In this case, the scattering coefficient takes much lower values especially at low frequencies. This is a sign that scattering is dominated by diffraction from the finite size effect at low frequencies, and the wells' influence is only effective at mid and high frequencies.

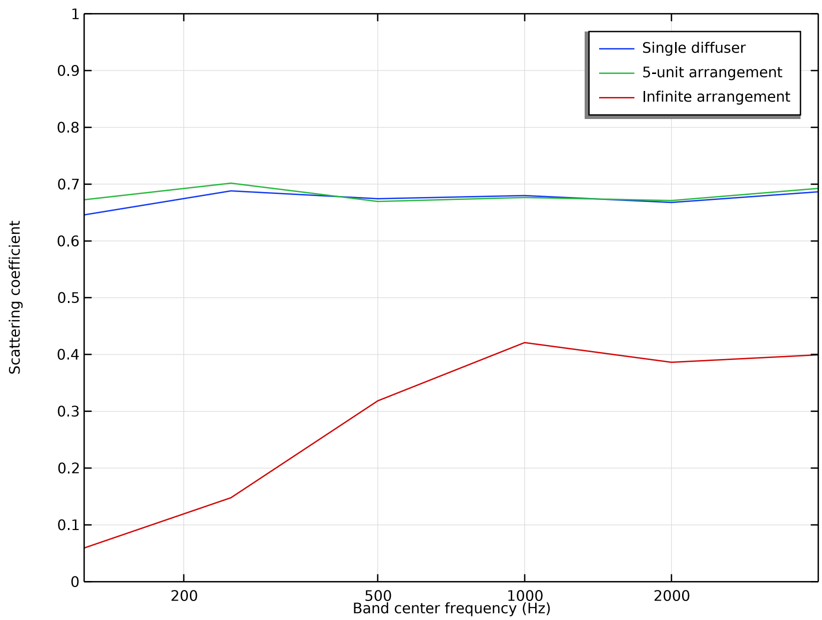


Figure 5: Random incidence scattering coefficient of the diffuser arrangements.

Notes About the COMSOL Implementation

This model was studied with the *Pressure Acoustics, Frequency Domain* interface. Alternatively, the *Pressure Acoustics, Boundary Elements* interface could also be used and return accurate results, but with the drawback that solving time would be larger for this small 2D model.

References

1. T.J. Cox and P. D'Antonio, *Acoustics Absorbers and Diffusers: Theory, Design and Application*, 2nd edition, Taylor & Francis, 2009.

2. F.A. Everest and K. C. Pohlmann, *Master Handbook of Acoustics*, 5th edition, McGraw Hill, 2009.

3. A.D. Pierce, *Acoustics: An Introduction to its Physical Principles and Applications*, 2nd edition, Acoustical Society of America, 1991.

Application Library path: `Acoustics_Module/Building_and_Room_Acoustics/diffuser_schroeder_2d`

Modeling Instructions

This section contains the modeling instructions for the Schroeder Diffuser in 2D model. They are followed by the Geometry Modeling Instructions section.

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**.

Start by importing the three geometry cases and the parameters needed for the study.

SINGLE DIFFUSER

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

2 In the **Settings** window for **Component**, type `Single diffuser` in the **Label** text field.

GEOMETRY 1

1. In the **Geometry** toolbar, click **Insert Sequence** and choose **Insert Sequence**.
2. Browse to the model's Application Libraries folder and double-click the file `diffuser_schroeder_2d_geom_sequence.mph`.
3. In the **Insert Sequence** dialog box, click **OK**.

1. In the **Model Builder** window, under **Single diffuser (comp1)** click **Geometry 1**.
2. In the **Geometry** toolbar, click **Build All**.

ADD COMPONENT

Right-click **Single diffuser (comp1)>Geometry 1** and choose **Add Component>2D**.

5-UNIT ARRANGEMENT

In the **Settings** window for **Component**, type `5-unit arrangement` in the **Label** text field.

GEOMETRY 2

1. In the **Geometry** toolbar, click **Insert Sequence** and choose **Insert Sequence**.
2. Browse to the model's Application Libraries folder and double-click the file `diffuser_schroeder_2d_geom_sequence.mph`.
3. In the **Insert Sequence** dialog box, select **Geometry 2** in the **Select geometry sequence to insert** list.
4. Click **OK**.

1. In the **Model Builder** window, under **5-unit arrangement (comp2)** click **Geometry 2**.
2. In the **Geometry** toolbar, click **Build All**.

ADD COMPONENT

Right-click **5-unit arrangement (comp2)>Geometry 2** and choose **Add Component>2D**.

INFINITE ARRANGEMENT

In the **Settings** window for **Component**, type `Infinite arrangement` in the **Label** text field.

GEOMETRY 3

1. In the **Geometry** toolbar, click **Insert Sequence** and choose **Insert Sequence**.
2. Browse to the model's Application Libraries folder and double-click the file `diffuser_schroeder_2d_geom_sequence.mph`.

3 In the **Insert Sequence** dialog box, select **Geometry 3** in the **Select geometry sequence to insert** list.

4 Click **OK**.

1 In the **Model Builder** window, under **Infinite arrangement (comp3)** click **Geometry 3**.

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

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 the right end of the **Add to Component** split button in the window toolbar.

5 From the menu, choose **Single diffuser (comp1)**.

6 Click **5-unit arrangement (comp2)** in the window toolbar.

7 Click **Infinite arrangement (comp3)** in the window toolbar.

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

GLOBAL DEFINITIONS

Parameters 1 - Geometry

In the **Settings** window for **Parameters**, type `Parameters 1 - Geometry` in the **Label** text field.

Parameters 2 - Physics

1 In the **Home** toolbar, click **Parameters** and choose **Add>Parameters**.

2 In the **Settings** window for **Parameters**, type `Parameters 2 - Physics` in the **Label** text field.

3 Locate the **Parameters** section. Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `diffuser_schroeder_2d_parameters_physics.txt`.

Proceed with setting up the physics and local variables. The incident plane wave is defined manually in order to include the specular reflection from the infinite baffle in the **Background Pressure Field**. This allows the solver to only compute the influence of the diffuser on the sound field.

DEFINITIONS (COMP1)

In the **Model Builder** window, under **Single diffuser (comp1)** click **Definitions**.

Integration 1 (intop1)

1 In the **Definitions** toolbar, click **Nonlocal Couplings** and choose **Integration**.
2 In the **Settings** window for **Integration**, locate the **Source Selection** section.
3 From the **Geometric entity level** list, choose **Boundary**.
4 Select Boundary 29 only.

Variables 1

1 Right-click **Definitions** and choose **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 `diffuser_schroeder_2d_variables_single.txt`.

PRESSURE ACOUSTICS, FREQUENCY DOMAIN (ACPR)

Background Pressure Field 1

1 In the **Model Builder** window, expand the **Single diffuser (comp1)>Pressure Acoustics, Frequency Domain (acpr)** node.
2 Right-click **Pressure Acoustics, Frequency Domain (acpr)** and choose **Background Pressure Field**.
3 Select Domain 1 only.
4 In the **Settings** window for **Background Pressure Field**, locate the **Background Pressure Field** section.
5 From the **Pressure field type** list, choose **User defined**.
6 In the p_b text field, type `p_inc+p_inf`.

Perfectly Matched Boundary 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Perfectly Matched Boundary**.
2 Select Boundaries 27 and 28 only.

Exterior Field Calculation 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Exterior Field Calculation**.
2 Select Boundaries 27 and 28 only.
3 In the **Settings** window for **Exterior Field Calculation**, locate the **Exterior Field Calculation** section.
4 From the **Condition in the y = y_0 plane** list, choose **Symmetric/Infinite sound hard boundary**.

Generate the mesh using the **Physics-controlled mesh** functionality. The frequency controlling the maximum element size is per default taken **From study**. Set the desired **Frequencies** in the study step. In general, 5 to 6 second-order elements per wavelength are needed to resolve the waves. For more details, see *Meshing (Resolving the Waves)* in the *Acoustics Module User's Guide*. In this model, use the default **Automatic** option, which gives 5 elements per wavelength.

STUDY 1

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	Parameter unit
n (Band number)	`range(0,1,5)`	

Step 1: Frequency Domain

1 In the **Model Builder** window, click **Step 1: Frequency Domain**.

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

3 In the **Frequencies** text field, type `10^{range(log10(fL[1/Hz])+df_log/2,df_log, log10(fU[1/Hz])-df_log/2)}`.

4 Click to expand the **Study Extensions** section. Select the **Auxiliary sweep** check box.

5 Click **Add**.

6 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
theta0 (Incidence polar angle from normal direction)	`range(-80,10,80)`	`deg`

MESH 1

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

Set up the physics and generate the mesh in a similar fashion for the second component with five diffuser units.

5-UNIT ARRANGEMENT (COMP2)

In the **Model Builder** window, click **5-unit arrangement (comp2)**.

ADD PHYSICS

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

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

3 In the tree, select **Acoustics>Pressure Acoustics>Pressure Acoustics, Frequency Domain (acpr)**.

4 Click **Add to 5-unit Arrangement** in the window toolbar.

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

DEFINITIONS (COMP2)

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 **Boundary**.

4 Select Boundary 125 only.

Variables 2

1 In the **Model Builder** window, right-click **Definitions** and choose **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 `diffuser_schroeder_2d_variables_5unit.txt`.

PRESSURE ACOUSTICS, FREQUENCY DOMAIN 2 (ACPR2)

In the **Model Builder** window, under **5-unit arrangement (comp2)** click **Pressure Acoustics, Frequency Domain 2 (acpr2)**.

Background Pressure Field 1

1 In the **Physics** toolbar, click **Domains** and choose **Background Pressure Field**.

2 Select Domain 1 only.

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

4 From the **Pressure field type** list, choose **User defined**.

5 In the p_b text field, type `p_inc+p_inf`.

Perfectly Matched Boundary 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Perfectly Matched Boundary**.
2 Select Boundaries 123 and 124 only.

Exterior Field Calculation 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Exterior Field Calculation**.
2 Select Boundaries 123 and 124 only.
3 In the **Settings** window for **Exterior Field Calculation**, locate the **Exterior Field Calculation** section.
4 From the **Condition in the y = y_0 plane** list, choose **Symmetric/ Infinite sound hard boundary**.

MESH 2

In the **Model Builder** window, under **5-unit arrangement (comp2)** right-click **Mesh 2** and choose **Build All**.

Define the third component with a periodic condition to model an infinite arrangement of diffusers. As a consequence, the sound pressure in the exterior field cannot be evaluated on a circular arc in this case; the calculation of the energy reflected in the specular direction is thus based on sound intensity.

INFINITE ARRANGEMENT (COMP3)

In the **Model Builder** window, click **Infinite arrangement (comp3)**.

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 **Acoustics>Pressure Acoustics>Pressure Acoustics, Frequency Domain (acpr)**.
4 Click **Add to Infinite Arrangement** in the window toolbar.
5 In the **Physics** toolbar, click **Add Physics** to close the **Add Physics** window.

DEFINITIONS (COMP3)

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 3 only.

Variables 3

1 In the **Model Builder** window, right-click **Definitions** and choose **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 `diffuser_schroeder_2d_variables_infinite.txt`.

PRESSURE ACOUSTICS, FREQUENCY DOMAIN 3 (ACPR3)

In the **Model Builder** window, under **Infinite arrangement (comp3)** click **Pressure Acoustics, Frequency Domain 3 (acpr3)**.

Background Pressure Field 1

1 In the **Physics** toolbar, click **Domains** and choose **Background Pressure Field**.

2 Select Domain 1 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 In the c text field, type `c0`.

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

`sin(theta0)`	x
`-cos(theta0)`	y

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

8 In the ρ text field, type `rho0`.

Perfectly Matched Boundary 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Perfectly Matched Boundary**.

2 Select Boundary 3 only.

3 In the **Settings** window for **Perfectly Matched Boundary**, locate the **Geometry** section.

4 From the **Attenuation direction** list, choose **Normal**.

Periodic Condition 1

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

2 Select Boundaries 1 and 28 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

sin(theta0)*acpr3.k	x
-cos(theta0)*acpr3.k	y

MESH 3

In the **Model Builder** window, under **Infinite arrangement (comp3)** right-click **Mesh 3** and choose **Build All**.

RESULTS

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

2 In the **Settings** window for **Results**, locate the **Update of Results** section.

3 Select the **Only plot when requested** check box.

Proceed with solving the study. Generate the default plots for Component 1 only so as to avoid duplicate plot groups.

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 **Physics and Variables Selection** section.

3 In the table, enter the following settings:

Physics interface	Solve for	Equation form
Pressure Acoustics, Frequency Domain 2 (acpr2)		Automatic (Frequency domain)
Pressure Acoustics, Frequency Domain 3 (acpr3)		Automatic (Frequency domain)

4 Click to expand the **Mesh Selection** section. In the table, enter the following settings:

Component	Mesh
5-unit arrangement	No mesh
Infinite arrangement	No mesh

5 In the **Study** toolbar, click **Show Default Plots**.

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

7 In the **Settings** window for **Study**, locate the **Study Settings** section.

8 Clear the **Generate default plots** check box.

9 In the **Model Builder** window, click **Step 1: Frequency Domain**.

10 In the **Settings** window for **Frequency Domain**, locate the **Physics and Variables Selection** section.

11 In the table, enter the following settings:

Physics interface	**Solve for**	**Equation form**
Pressure Acoustics, Frequency Domain 2 (acpr2)	√	Automatic (Frequency domain)
Pressure Acoustics, Frequency Domain 3 (acpr3)	√	Automatic (Frequency domain)

12 Locate the **Mesh Selection** section. In the table, enter the following settings:

Component	**Mesh**
5-unit arrangement	Mesh 2
Infinite arrangement	Mesh 3

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

Before investigating the results, remove the circular arcs from the datasets. They only serve a purpose for calculating integrals and do not need to be shown in the result plots.

RESULTS

Study 1/Parametric Solutions 1 (4) - Single diffuser

1 In the **Model Builder** window, expand the **Results>Datasets** node, then click **Study 1/ Parametric Solutions 1 (4) (sol2)**.

2 In the **Settings** window for **Solution**, type `Study 1/Parametric Solutions 1 (4) - Single diffuser` in the **Label** text field.

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 Domain 1 only.

Study 1/Parametric Solutions 1 (5) - 5-unit arrangement

1 In the **Model Builder** window, under **Results>Datasets** click **Study 1/ Parametric Solutions 1 (5) (sol2)**.

2 In the **Settings** window for **Solution**, type `Study 1/Parametric Solutions 1 (5) - 5-unit arrangement` in the **Label** text field.

Selection

1 Right-click **Study 1/Parametric Solutions 1 (5) - 5-unit arrangement** 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 Domain 1 only.

Create an Array dataset to show multiple periods of the infinite arrangement of diffusers.

Study 1/Parametric Solutions 1 (6) - Infinite arrangement

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

2 In the **Settings** window for **Solution**, type `Study 1/Parametric Solutions 1 (6) - Infinite arrangement` in the **Label** text field.

Array 2D - 5 periods of the infinite arrangement

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 (6) - Infinite arrangement (sol2)**.

4 In the **Label** text field, type `Array 2D - 5 periods of the infinite arrangement`.

5 Locate the **Array Size** section. In the **X size** text field, type `5`.

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

7 Find the **Wave vector** subsection. In the **X** text field, type `sin(theta0)*2*pi*freq/c0`.

8 In the **Y** text field, type `-cos(theta0)*2*pi*freq/c0`.

Acoustic Pressure (acpr)

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

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

3 From the **Parameter value (n)** list, choose **3**.

4 From the **Parameter value (freq (Hz),theta0 (deg))** list, choose **94: freq=1334.8 Hz, theta0=0 deg**.

Surface 1

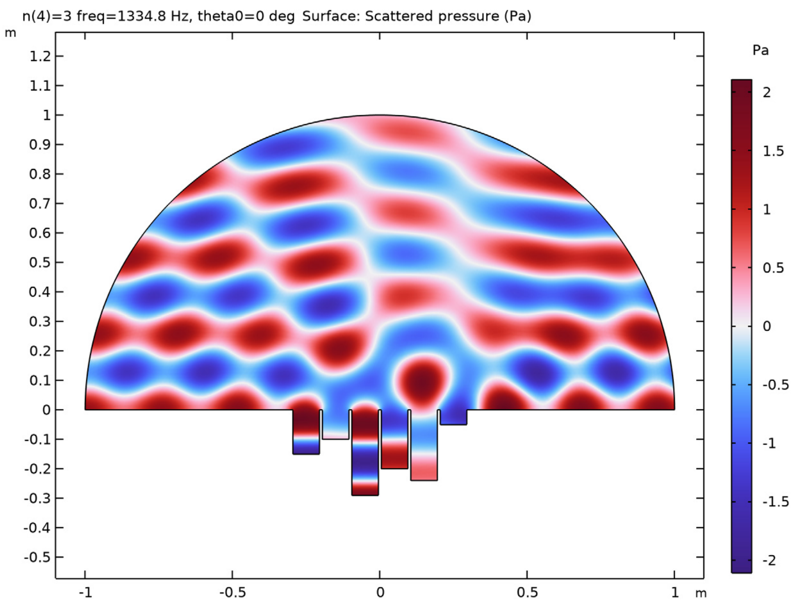
1 In the **Model Builder** window, expand the **Acoustic Pressure (acpr)** node, then click **Surface 1**.

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

3 In the **Expression** text field, type `p_scat`.

4 In the **Acoustic Pressure (acpr)** toolbar, click **Plot**.

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



Acoustic Pressure (acpr)

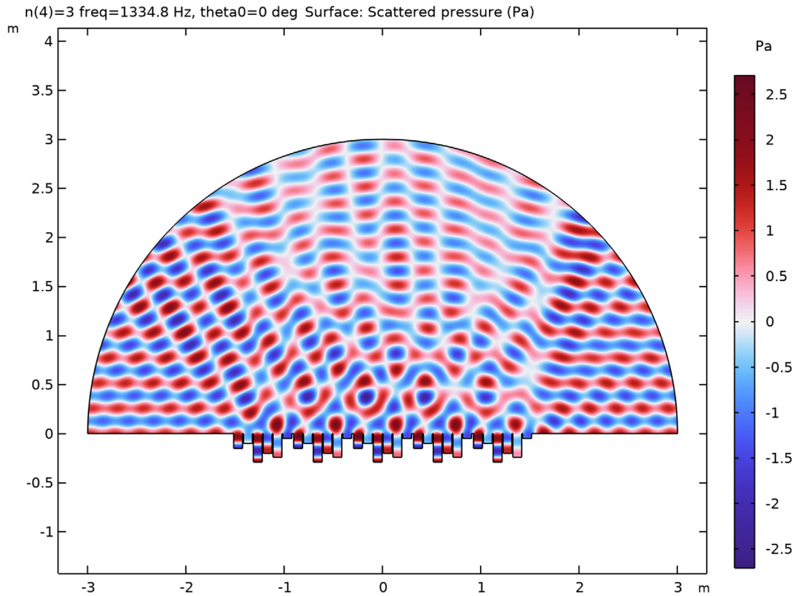
1 In the **Model Builder** window, click **Acoustic Pressure (acpr)**.

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

3 From the **Dataset** list, choose **Study 1/Parametric Solutions 1 (5) - 5-unit arrangement (sol2)**.

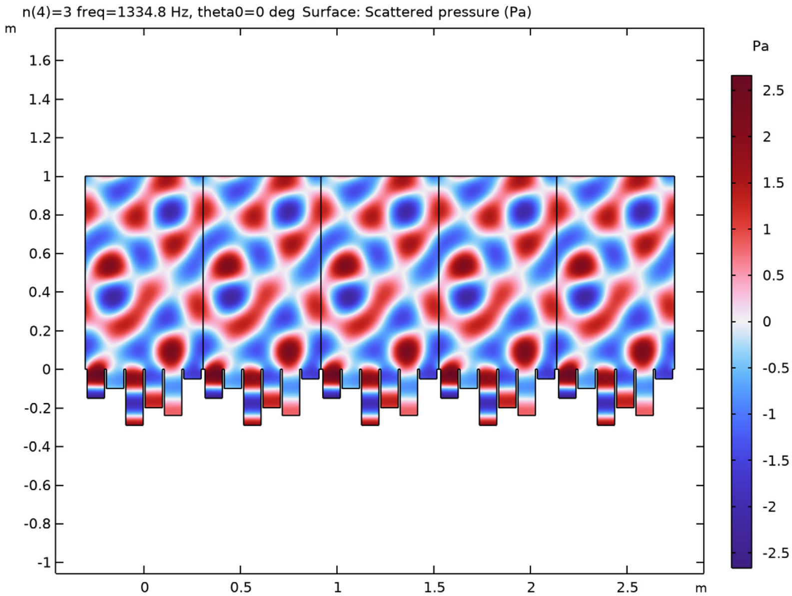
4 In the **Acoustic Pressure (acpr)** toolbar, click **Plot**.

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



6 From the **Dataset** list, choose **Array 2D - 5 periods of the infinite arrangement**.

7 In the **Acoustic Pressure (acpr)** toolbar, click **Plot**.



Sound Pressure Level (acpr)

1 In the **Model Builder** window, click **Sound Pressure Level (acpr)**.

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

3 From the **Parameter value (n)** list, choose **3**.

4 From the **Parameter value (freq (Hz),theta0 (deg))** list, choose **94: freq=1334.8 Hz, theta0=0 deg**.

Surface 1

1 In the **Model Builder** window, expand the **Sound Pressure Level (acpr)** node, then click **Surface 1**.

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

3 In the **Expression** text field, type `Lp_scat`.

4 In the **Sound Pressure Level (acpr)** toolbar, click **Plot**.

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

Sound Pressure Level (acpr)

1 In the **Model Builder** window, click **Sound Pressure Level (acpr)**.

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

3 From the **Dataset** list, choose **Study 1/Parametric Solutions 1 (5) - 5-unit arrangement (sol2)**.

4 In the **Sound Pressure Level (acpr)** toolbar, click **Plot**.

5 From the **Dataset** list, choose **Array 2D - 5 periods of the infinite arrangement**.

6 In the **Sound Pressure Level (acpr)** toolbar, click **Plot**.

Exterior-Field Sound Pressure Level (acpr)

1 In the **Model Builder** window, click **Exterior-Field Sound Pressure Level (acpr)**.

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

3 From the **Parameter selection (n)** list, choose **From list**.

4 In the **Parameter values** list, select **1**.

5 From the **Parameter selection (freq, theta0)** list, choose **Manual**.

6 In the **Parameter indices (1-102)** text field, type `range(12,17,102)`.

7 Locate the **Axis** section. Select the **Symmetric angle range** check box.

8 From the **Zero angle** list, choose **Up**.

9 Locate the **Legend** section. From the **Position** list, choose **Manual**.

10 In the **x-position** text field, type `0.5`.

11 In the **y-position** text field, type `0.25`.

Radiation Pattern 1

1 In the **Model Builder** window, expand the **Exterior-Field Sound Pressure Level (acpr)** node, then click **Radiation Pattern 1**.

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

3 In the **Expression** text field, type `Lp_ext`.

4 Locate the **Evaluation** section. Find the **Angles** subsection. In the **Number of angles** text field, type `360`.

5 From the **Restriction** list, choose **Manual**.

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

7 In the **ϕ range** text field, type `180`.

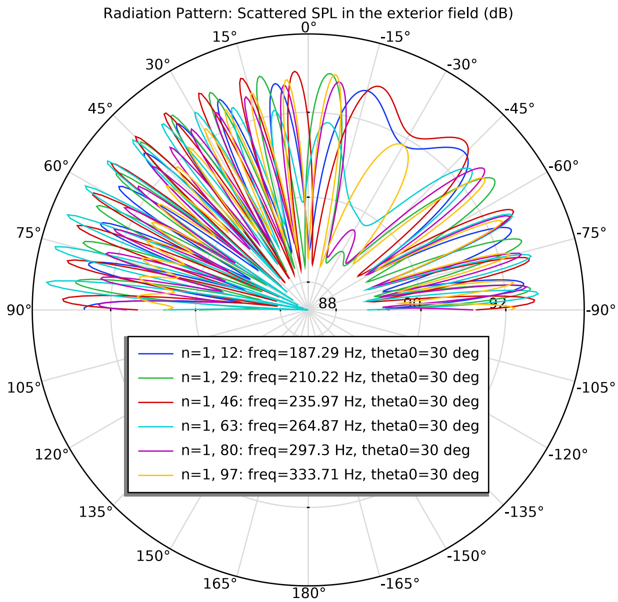
8 Find the **Circle** subsection. From the **Circle** list, choose **Manual**.

9 Find the **Evaluation distance** subsection. In the **Radius** text field, type `r0`.

10 Find the **Reference direction** subsection. In the **x** text field, type `0`.

11 In the **y** text field, type `1`.

12 In the **Exterior-Field Sound Pressure Level (acpr)** toolbar, click **Plot**.



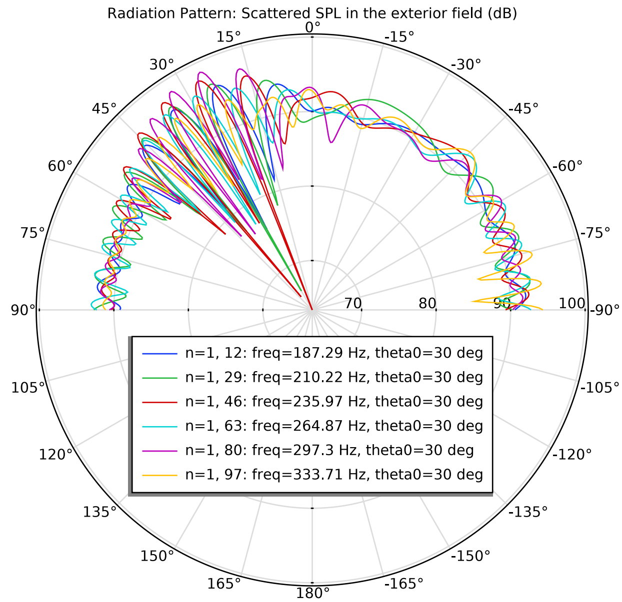
Exterior-Field Sound Pressure Level (acpr)

1 In the **Model Builder** window, click **Exterior-Field Sound Pressure Level (acpr)**.

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

3 From the **Dataset** list, choose **Study 1/Parametric Solutions 1 (5) - 5-unit arrangement (sol2)**.

4 In the **Exterior-Field Sound Pressure Level (acpr)** toolbar, click **Plot**.



Exterior-Field Pressure (acpr)

1 In the **Model Builder** window, click **Exterior-Field Pressure (acpr)**.

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

3 From the **Parameter selection (n)** list, choose **From list**.

4 In the **Parameter values** list, select **1**.

5 From the **Parameter selection (freq, theta0)** list, choose **Manual**.

6 In the **Parameter indices (1-102)** text field, type `range(12,17,102)`.

7 Locate the **Axis** section. Select the **Symmetric angle range** check box.

8 From the **Zero angle** list, choose **Up**.

9 Locate the **Legend** section. From the **Position** list, choose **Manual**.

10 In the **x-position** text field, type `0.5`.

11 In the **y-position** text field, type `0.25`.

Radiation Pattern 1

1 In the **Model Builder** window, expand the **Exterior-Field Pressure (acpr)** node, then click **Radiation Pattern 1**.

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

3 In the **Expression** text field, type `abs(p_scat_ext)^2`.

4 Locate the **Evaluation** section. Find the **Angles** subsection. In the **Number of angles** text field, type `360`.

5 From the **Restriction** list, choose **Manual**.

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

7 In the ϕ **range** text field, type `180`.

8 Find the **Circle** subsection. From the **Circle** list, choose **Manual**.

9 Find the **Evaluation distance** subsection. In the **Radius** text field, type `r0`.

10 Find the **Reference direction** subsection. In the **x** text field, type `0`.

11 In the **y** text field, type `1`.

12 In the **Exterior-Field Pressure (acpr)** toolbar, click **Plot**.

Exterior-Field Pressure (acpr)

1 In the **Model Builder** window, click **Exterior-Field Pressure (acpr)**.

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

3 From the **Dataset** list, choose **Study 1/Parametric Solutions 1 (5) - 5-unit arrangement (sol2)**.

4 In the **Exterior-Field Pressure (acpr)** toolbar, click **Plot**.

Evaluation Group 1

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

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

3 From the **Dataset** list, choose **Study 1/Parametric Solutions 1 (4) - Single diffuser (sol2)**.

4 Click to expand the **Format** section. From the **Include parameters** list, choose **Off**.

Global Evaluation 1

1 Right-click **Evaluation Group 1** and choose **Global Evaluation**.

2 In the **Settings** window for **Global Evaluation**, locate the **Data** section.

3 From the **Table columns** list, choose **Outer solutions**.

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

Expression	Unit	Description
`fC`	`Hz`	`Band center frequency`
`1-Pw_spec/Pw_tot`	`1`	

5 Locate the **Data Series Operation** section. From the **Transformation** list, choose **Average**.

6 In the **Evaluation Group 1** toolbar, click **Evaluate**.

Evaluation Group 1

In the **Model Builder** window, right-click **Evaluation Group 1** and choose **Duplicate**.

Evaluation Group 2

1 In the **Model Builder** window, click **Evaluation Group 2**.

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

3 From the **Dataset** list, choose **Study 1/Parametric Solutions 1 (5) - 5-unit arrangement (sol2)**.

4 In the **Evaluation Group 2** toolbar, click **Evaluate**.

5 Right-click **Evaluation Group 2** and choose **Duplicate**.

Evaluation Group 3

1 In the **Model Builder** window, click **Evaluation Group 3**.

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

3 From the **Dataset** list, choose **Study 1/Parametric Solutions 1 (6) - Infinite arrangement (sol2)**.

Global Evaluation 1

1 In the **Model Builder** window, expand the **Evaluation Group 3** node, then click **Global Evaluation 1**.

2 In the **Settings** window for **Global Evaluation**, locate the **Expressions** section.

3 In the table, enter the following settings:

Expression	Unit	Description
`1-I_spec/I_tot`	1	

4 In the **Evaluation Group 3** toolbar, click **Evaluate**.

Scattering coefficients

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

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

3 Locate the **Data** section. From the **Dataset** list, choose **None**.

4 Locate the **Plot Settings** section.

5 Select the **x-axis label** check box. In the associated text field, type `Band center frequency (Hz)`.

6 Select the **y-axis label** check box. In the associated text field, type `Scattering coefficient`.

7 Locate the **Axis** section. Select the **Manual axis limits** check box.

8 In the **x minimum** text field, type `125`.

9 In the **x maximum** text field, type `4000`.

10 In the **y minimum** text field, type `0`.

11 Select the **x-axis log scale** check box.

Table Graph 1

1 Right-click **Scattering coefficients** and choose **Table Graph**.

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

3 From the **Source** list, choose **Evaluation group**.

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

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

6 In the table, enter the following settings:

Legends
Single diffuser

Table Graph 2

1 In the **Model Builder** window, right-click **Scattering coefficients** and choose **Table Graph**.

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

3 From the **Source** list, choose **Evaluation group**.

4 From the **Evaluation group** list, choose **Evaluation Group 2**.

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

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

7 In the table, enter the following settings:

Legends
5-unit arrangement

Table Graph 3

1 Right-click **Scattering coefficients** and choose **Table Graph**.

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

3 From the **Source** list, choose **Evaluation group**.

4 From the **Evaluation group** list, choose **Evaluation Group 3**.

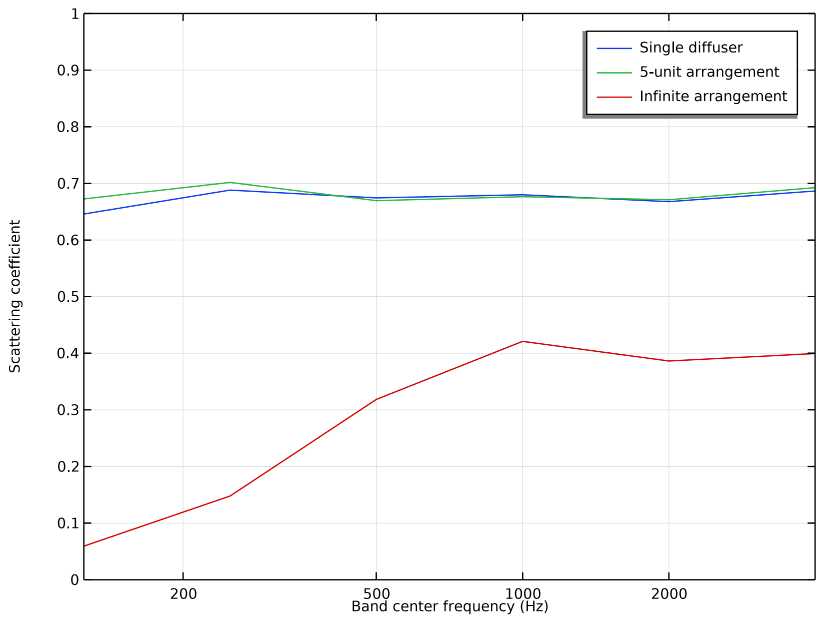
5 Locate the **Legends** section. Select the **Show legends** check box.

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

7 In the table, enter the following settings:

Legends
`Infinite arrangement`

8 In the **Scattering coefficients** toolbar, click **Plot**.



Geometry Modeling Instructions

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

NEW

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

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 Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `diffuser_schroeder_2d_geom_sequence_parameters.txt`.

ADD COMPONENT

In the **Home** toolbar, click **Add Component** and choose **2D**.

SINGLE DIFFUSER

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

2 In the **Settings** window for **Component**, type `Single diffuser` in the **Label** text field.

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 `d1`.

5 In the **Width** text field, type `Lw`.

6 Locate the **Position** section. In the **x** text field, type `-L/2+Li`.

7 In the **y** text field, type `-d1`.

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 `Lw`.

4 In the **Height** text field, type `d2`.

5 Locate the **Position** section. In the **x** text field, type `-L/2+2*Li+Lw`.

6 In the **y** text field, type `-d2`.

Rectangle 3 (r3)

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 `Lw`.

4 In the **Height** text field, type `d3`.

5 Locate the **Position** section. In the **x** text field, type `-L/2+3*Li+2*Lw`.

6 In the **y** text field, type `-d3`.

Rectangle 4 (r4)

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 `Lw`.

4 In the **Height** text field, type `d4`.

5 Locate the **Position** section. In the **x** text field, type `-L/2+4*Li+3*Lw`.

6 In the **y** text field, type `-d4`.

Rectangle 5 (r5)

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 `Lw`.

4 In the **Height** text field, type `d5`.

5 Locate the **Position** section. In the **x** text field, type `-L/2+5*Li+4*Lw`.

6 In the **y** text field, type `-d5`.

Rectangle 6 (r6)

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 `Lw`.

4 In the **Height** text field, type `d6`.

5 Locate the **Position** section. In the **x** text field, type `-L/2+6*Li+5*Lw`.

6 In the **y** text field, type `-d6`.

Rectangle 1 (r1), Rectangle 2 (r2), Rectangle 3 (r3), Rectangle 4 (r4), Rectangle 5 (r5), Rectangle 6 (r6)

1 In the **Model Builder** window, under **Single diffuser (comp1)>Geometry 1**, Ctrl-click to select **Rectangle 1 (r1)**, **Rectangle 2 (r2)**, **Rectangle 3 (r3)**, **Rectangle 4 (r4)**, **Rectangle 5 (r5)**, and **Rectangle 6 (r6)**.

2 Right-click and choose **Group**.

Wells

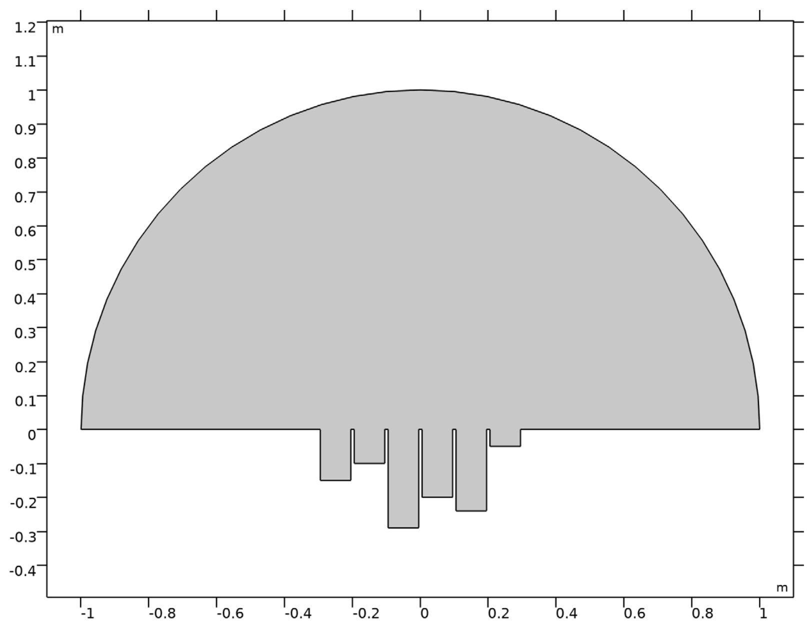
In the **Settings** window for **Group**, type `Wells` in the **Label** text field.

Circle 1 (c1)

1. In the **Geometry** toolbar, click **Circle**.
2. In the **Settings** window for **Circle**, locate the **Size and Shape** section.
3. In the **Radius** text field, type `r_air`.
4. In the **Sector angle** text field, type `180`.

Union 1 (uni1)

1. In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Union**.
2. Click in the **Graphics** window and then press Ctrl+A to select all objects.
3. In the **Settings** window for **Union**, locate the **Union** section.
4. Clear the **Keep interior boundaries** check box.
5. In the **Geometry** toolbar, click **Build All**.
6. Click the **Zoom Extents** button in the **Graphics** toolbar.
7. In the **Model Builder** window, click **Geometry 1**.



Circular Arc 1 (ca1)

1. In the **Geometry** toolbar, click **More Primitives** and choose **Circular Arc**.

2 In the **Settings** window for **Circular Arc**, locate the **Radius** section.

3 In the **Radius** text field, type `r0`.

4 Locate the **Angles** section. In the **End angle** text field, type `180`.

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

ADD COMPONENT

Right-click **Geometry 1** and choose **Add Component>2D**.

5-UNIT ARRANGEMENT

In the **Settings** window for **Component**, type `5-unit arrangement` in the **Label** text field.

GEOMETRY 1

Wells

In the **Model Builder** window, under **Single diffuser (comp1)>Geometry 1** right-click **Wells** and choose **Copy**.

GEOMETRY 2

In the **Model Builder** window, under **5-unit arrangement (comp2)** right-click **Geometry 2** and choose **Paste Group**.

In the **Model Builder** window, under **5-unit arrangement (comp2)>Geometry 2** right-click **Wells** and choose **Duplicate**.

Wells 1 to the left

1 In the **Model Builder** window, expand the **5-unit arrangement (comp2)>Geometry 2>Wells 1** node, then click **Wells 1**.

2 In the **Settings** window for **Group**, type `Wells 1 to the left` in the **Label** text field.

Rectangle 7 (r7)

1 In the **Model Builder** window, click **Rectangle 7 (r7)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `-3*L/2+Li`.

Rectangle 8 (r8)

1 In the **Model Builder** window, click **Rectangle 8 (r8)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `-3*L/2+2*Li+Lw`.

Rectangle 9 (r9)

1 In the **Model Builder** window, click **Rectangle 9 (r9)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `-3*L/2+3*Li+2*Lw`.

Rectangle 10 (r10)

1 In the **Model Builder** window, click **Rectangle 10 (r10)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `-3*L/2+4*Li+3*Lw`.

Rectangle 11 (r11)

1 In the **Model Builder** window, click **Rectangle 11 (r11)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `-3*L/2+5*Li+4*Lw`.

Rectangle 12 (r12)

1 In the **Model Builder** window, click **Rectangle 12 (r12)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `-3*L/2+6*Li+5*Lw`.

Wells

In the **Model Builder** window, under **5-unit arrangement (comp2)>Geometry 2** right-click **Wells** and choose **Duplicate**.

Wells 2 to the left

1 In the **Model Builder** window, expand the **5-unit arrangement (comp2)>Geometry 2> Wells 1** node, then click **Wells 1**.

2 In the **Settings** window for **Group**, type `Wells 2 to the left` in the **Label** text field.

Rectangle 13 (r13)

1 In the **Model Builder** window, click **Rectangle 13 (r13)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `-5*L/2+Li`.

Rectangle 14 (r14)

1 In the **Model Builder** window, click **Rectangle 14 (r14)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `-5*L/2+2*Li+Lw`.

Rectangle 15 (r15)

1 In the **Model Builder** window, click **Rectangle 15 (r15)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `-5*L/2+3*Li+2*Lw`.

Rectangle 16 (r16)

1 In the **Model Builder** window, click **Rectangle 16 (r16)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `-5*L/2+4*Li+3*Lw`.

Rectangle 17 (r17)

1 In the **Model Builder** window, click **Rectangle 17 (r17)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `-5*L/2+5*Li+4*Lw`.

Rectangle 18 (r18)

1 In the **Model Builder** window, click **Rectangle 18 (r18)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `-5*L/2+6*Li+5*Lw`.

Wells

In the **Model Builder** window, under **5-unit arrangement (comp2)>Geometry 2** right-click **Wells** and choose **Duplicate**.

Wells 1 to the right

1 In the **Model Builder** window, expand the **5-unit arrangement (comp2)>Geometry 2>Wells 1** node, then click **Wells 1**.

2 In the **Settings** window for **Group**, type `Wells 1 to the right` in the **Label** text field.

Rectangle 19 (r19)

1 In the **Model Builder** window, click **Rectangle 19 (r19)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `L/2+Li`.

Rectangle 20 (r20)

1 In the **Model Builder** window, click **Rectangle 20 (r20)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `L/2+2*Li+Lw`.

Rectangle 21 (r21)

1 In the **Model Builder** window, click **Rectangle 21 (r21)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `L/2+3*Li+2*Lw`.

Rectangle 22 (r22)

1 In the **Model Builder** window, click **Rectangle 22 (r22)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `L/2+4*Li+3*Lw`.

Rectangle 23 (r23)

1 In the **Model Builder** window, click **Rectangle 23 (r23)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `L/2+5*Li+4*Lw`.

Rectangle 24 (r24)

1 In the **Model Builder** window, click **Rectangle 24 (r24)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `L/2+6*Li+5*Lw`.

Wells

In the **Model Builder** window, under **5-unit arrangement (comp2)>Geometry 2** right-click **Wells** and choose **Duplicate**.

Wells 2 to the right

1 In the **Model Builder** window, expand the **5-unit arrangement (comp2)>Geometry 2>Wells 1** node, then click **Wells 1**.

2 In the **Settings** window for **Group**, type `Wells 2 to the right` in the **Label** text field.

Rectangle 25 (r25)

1 In the **Model Builder** window, click **Rectangle 25 (r25)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `3*L/2+Li`.

Rectangle 26 (r26)

1 In the **Model Builder** window, click **Rectangle 26 (r26)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `3*L/2+2*Li+Lw`.

Rectangle 27 (r27)

1 In the **Model Builder** window, click **Rectangle 27 (r27)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `3*L/2+3*Li+2*Lw`.

Rectangle 28 (r28)

1 In the **Model Builder** window, click **Rectangle 28 (r28)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `3*L/2+4*Li+3*Lw`.

Rectangle 29 (r29)

1 In the **Model Builder** window, click **Rectangle 29 (r29)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `3*L/2+5*Li+4*Lw`.

Rectangle 30 (r30)

1 In the **Model Builder** window, click **Rectangle 30 (r30)**.

2 In the **Settings** window for **Rectangle**, locate the **Position** section.

3 In the **x** text field, type `3*L/2+6*Li+5*Lw`.

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 `3*r_air`.

4 In the **Sector angle** text field, type `180`.

Union 1 (uni1)

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

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

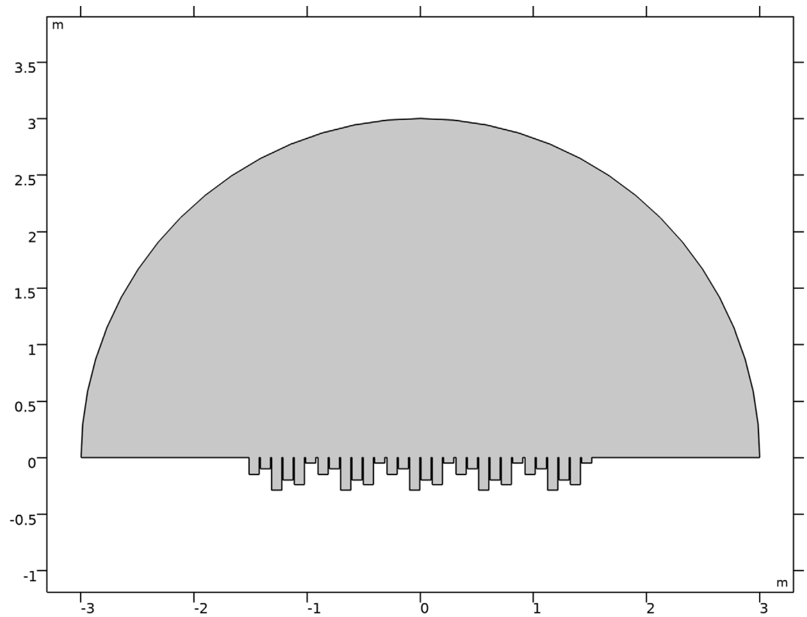
3 In the **Settings** window for **Union**, locate the **Union** section.

4 Clear the **Keep interior boundaries** check box.

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

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

7 In the **Model Builder** window, click **Geometry 2**.



Circular Arc 1 (ca1)

1 In the **Geometry** toolbar, click **More Primitives** and choose **Circular Arc**.

2 In the **Settings** window for **Circular Arc**, locate the **Radius** section.

3 In the **Radius** text field, type `r0`.

4 Locate the **Angles** section. In the **End angle** text field, type `180`.

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

ADD COMPONENT

Right-click **Geometry 2** and choose **Add Component>2D**.

INFINITE ARRANGEMENT

In the **Settings** window for **Component**, type `Infinite arrangement` in the **Label** text field.

GEOMETRY 1

Wells

In the **Model Builder** window, under **Single diffuser (comp1)>Geometry 1** right-click **Wells** and choose **Copy**.

GEOMETRY 3

In the **Model Builder** window, under **Infinite arrangement (comp3)** right-click **Geometry 3** and choose **Paste Group**.

Rectangle 7 (r7)

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 `L`.

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

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

Union 1 (uni1)

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

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

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

4 Clear the **Keep interior boundaries** check box.

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

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

7 In the **Model Builder** window, click **Geometry 3**.