MECH6066 HW#3

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10.19.25

Problem 1

We know that the sound pressure level is equal to the sound intensity level. We will assume the standard value of I_{ref} for air of 10^{-12}W/m^2.

$$SPL = SIL = 10\log_{10}\left(\frac{I}{I_{ref}}\right)$$
$$120 = 10\log_{10}\left(\frac{I}{10^{-12}}\right)$$
$$I = 10^{-12}\cdot 10^{\frac{120}{10}} = 1\text{W/m}^2$$

Now we can add our efficiency and calculate the size required to generate 3W of power.

$$P_{req} = \frac{3}{0.95} = 3.158\text{W}$$
$$A_{req} = 3.158/1 = 3.158\text{m}^2$$
$$r_{req} = \sqrt{A_{req}/\pi} = 1\text{m}$$
$$\boxed{\text{required diameter } D_{req} = 2\text{m}}$$

Repeating the same calculations with 80dB instead of 120dB gives:

$$\boxed{\text{required diameter } D_{req} = 200.5\text{m}}$$

Based on these results, harvesting power from acoustic energy is not very reasonable. It requires a very loud environment to have a reasonably sized device, but the device is only able to slow charge 1 phone. There are not many environments where it is consistently 120dB to generate power, and even needing a 2 meter circle to charge one phone is fairly ridiculous. Clearly the problem is even worse when considering regular ambient noise that requires a 200 meter device to charge one phone. These also assume a 95% efficiency on the device, which is likely not possible to achieve.

Problem 2

(a)

From the textbook for water (1) and aluminum (2):

$$Z_1 = 1.48E6; \quad Z_2 = 17E6$$

The percentage reflected is given by the reflection coefficient:

$$R_I = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2 = \left(\frac{17 - 1.48}{17 + 1.48}\right)^2 = 0.705$$

$$\boxed{\text{amount of intensity reflected is 70.5\%}}$$

(b)

For maximum transmission, we will do quarter-wavelength matching. The ideal material will have an impedance given by:

$$Z_L = \sqrt{Z_1 \cdot Z_2} = \sqrt{1.48E6 \cdot 17E6} = 5.016E6$$

$$\boxed{Z_L = 5.016E6 \text{ Ry}}$$

The material will have a length equal to 1/4 of the wavelength at the desired frequency to transmit. We can determine that the required speed of sound of the material is given by the same equation as the impedance.

$$c_L = \sqrt{1481 * 6300} = 3054.6\text{m/s}$$

$$L = \frac{c}{4f} = \frac{3054.6}{4 \cdot 2E6} = 0.000382\text{m}$$

$$\boxed{\text{ideal thickness } L = 0.382\text{mm}}$$

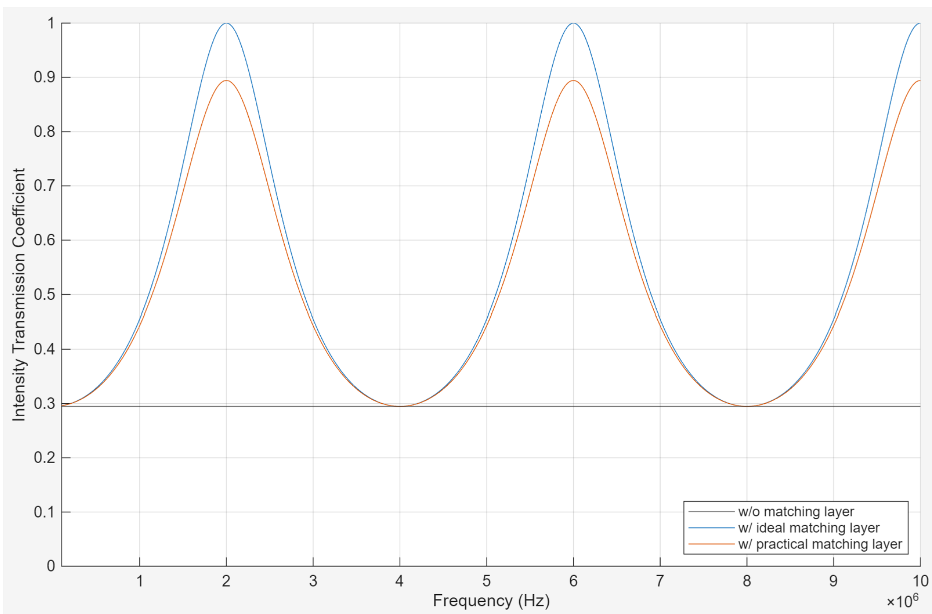
(c)

There are no perfect materials in the appendix. The closest is quartz sand. It has an impedance of 3.58E6Ry and speed of sound of 1730 m/s. Its required length would be:

$$L = \frac{c}{4f} = \frac{1730}{4 \cdot 2E6} = 0.0002163\text{m}$$

$$\boxed{\text{required thickness } L = 0.2163\text{mm}}$$

(d)



(e)

We can see without a matching layer, only around 30% of the intensity is transmitted. For the ideal layer, this goes up to 100% at our design point of 2MHz with a steep falloff on either side. The layer using the quartz sand, the most practical option from the book, transmits around 90% at the design frequencies. Overall, the matching layer is fairly good at transmitting despite having a different impedance. There is also good transmission at off-design frequencies. This is because the quarter-wavelength matching that is done to set the length is valid for any odd integer multiples of the design frequency. This makes sense as we can see transmission peaks at 6MHz (3x) and 10MHz (5x), with the layer behaving as if it is not there at even multiples of the design frequency.

Problem 3

(a)

The results for the no transmission layer match what I expect. The pressure wave goes between the two mediums and changes wavelength as expected for each domain. Since the plot is of total acoustic pressure, we are unable to see the change in intensity in this plot. I would expect an animation of this plot would show a standing wave in the water.

(b)

i

The amplitude of the pressure wave is constant at the input 1Pa. The instantaneous value changes over time as it is a pressure wave, so the value fluctuates between -1 and 1Pa at 2MHz as time goes on.

ii

The pressure amplitude fluctuates in the water because a large amount is reflected and creates a standing wave in the water. This wave leads to a fluctuation in the amplitude of the pressure. However, since aluminum has some intensity transferred to it but nothing reflected within, it has constant amplitude.

iii

The incident and scattered have different magnitudes in each medium. In the aluminum, there is no indicent so its magnitude is 0. The incident wave in water has the magnitude we input. The scattered is also different. Water has a lower ampltiude than aluminum for its scattered wave, and a fluctuation is clearly visible (since it is a standing wave). Aluminum has a much higher amplitude for its scattered wave which makes sense since this setup has a positive transmission coefficient.

iv

From the plot, the scattered amplitude is around 0.84 Pa on average. This gives $\hat{R} = \frac{0.84}{1} = 0.84$. Using comsol parameters to calculate the analytical reflection coefficient, we can see that it is 0.84011, which is almost identical to the measured value from the comsol sim.

(c)

We can see that comsol is very close to the analytical solution for the transmitted intensity. It varies from 29.4% to 32.2% across the range of frequencies. The analytical solution is a constant value of 29.4%. The variation shown in comsol is very likely due to the meshing of the problem. I assume the mesh is generated for the first input frequency, so it should be less accurate at other simulation frequencies. We can see for the second model with an ideal transmission layer, comsole predicts a similar shape to the analytical solution but it overpredicts the transmission at the design frequency (reporting slightly over 100%). Running the same model with quartz sand instead of the ideal values shows the same results—the same shape to the analytical solution but with an overprediction at the design frequency.

Problem 4

I preferred having the hints separate. I thought having more detail given with them and having the option to reference it when I felt stuck was a good way to work through the problems and very similar to how I would interact with classmates or AI for support on an assignment. I thought this assignment was very good and probably my favorite in terms of applying what we learned in class and understanding its real-world application.

Matlab Code

```
%%
% Slade Brooks
% brooksl@mail.uc.edu
% 10.19.25
% MECH6066
% HW 03

clear variables
close all

%% set up vals
% range of frequencies
fs = 0.1e6:0.01e6:10e6;
f = 2e6;
```

```
% acoustic properties
Z1 = 1.48e6; c1 = 1481;
Z2 = 17e6; c2 = 6300;
ZL = sqrt(Z1*Z2); cL = sqrt(c1*c2); L = cL/(4*f);
Zs = 3.58e6; cs = 1730; Ls = cs/(4*f);

%% calculate transmission
% w/o matching layer
TIi = 4*Z1*Z2/(Z1 + Z2)^2;

% w/ ideal matching layer
w = (2*pi).*fs;
K = w./cL;
TIii = 4./(2 + (Z2/Z1 + Z1/Z2).*(cos(K*L)).^2 + ((ZL^2)/(Z1*Z2) + (Z1*Z2)/(ZL^2)).*(sin(

% w/ practical matching layer
w = (2*pi).*fs;
K = w./cs;
TIiii = 4./(2 + (Z2/Z1 + Z1/Z2).*(cos(K*Ls)).^2 + ((Zs^2)/(Z1*Z2) + (Z1*Z2)/(Zs^2)).*(si

%% plotting
figure
hold on
yline(TIi); plot(fs, TIii); plot(fs, TIiii);
hold off
xlabel("Frequency (Hz)"); xlim([fs(1) fs(end)]);
ylabel("Intensity Transmission Coefficient"); ylim([0 1]);
legend(["w/o matching layer" "w/ ideal matching layer" "w/ practical matching layer"], l
grid on
```

Hw3

Report date	Oct 19, 2025, 6:01:36 PM

Contents

1 Global Definitions

Date	Oct 19, 2025, 4:43:06 PM

GLOBAL SETTINGS

Name	Hw3.mph
Path	\\clusterfsnew.ceas1.uc.edu\students\brooksl\desktop\hw3.mph
Version	COMSOL Multiphysics 6.3 (Build: 420)

USED PRODUCTS

COMSOL Multiphysics
Acoustics Module

COMPUTER INFORMATION

CPU	Intel64 Family 6 Model 198 Stepping 2, 28 cores, 63.46 GB RAM
Operating system	Windows 11

1.1 PARAMETERS

PARAMETERS 1

Name	Expression	Value	Description
ra	2700[kg/m^3]	2700 kg/m^3	
ca	6300[m/s]	6300 m/s	
rw	998[kg/m^3]	998 kg/m^3	
cw	1481[m/s]	1481 m/s	
pin	1[Pa]	1 Pa	
fin	2[MHz]	2E6 Hz	
W	1[cm]	0.01 m	
H	2[mm]	0.002 m	
Zw	rw*cw	1.478E6 $kg/(m^2 \cdot s)$	
Za	ra*ca	1.701E7 $kg/(m^2 \cdot s)$	
R	(Za - Zw)/(Zw + Za)	0.84011	
T	(2*Za)/(Zw + Za)	1.8401	
Ri	((Za - Zw)/(Zw + Za))^2	0.70578	
Ti	4*Za*Zw/(Zw + Za)^2	0.29422	

2 Component 1

SETTINGS

Description	Value
Unit system	Same as global system (SI)

2.1 DEFINITIONS

2.1.1 Coordinate Systems

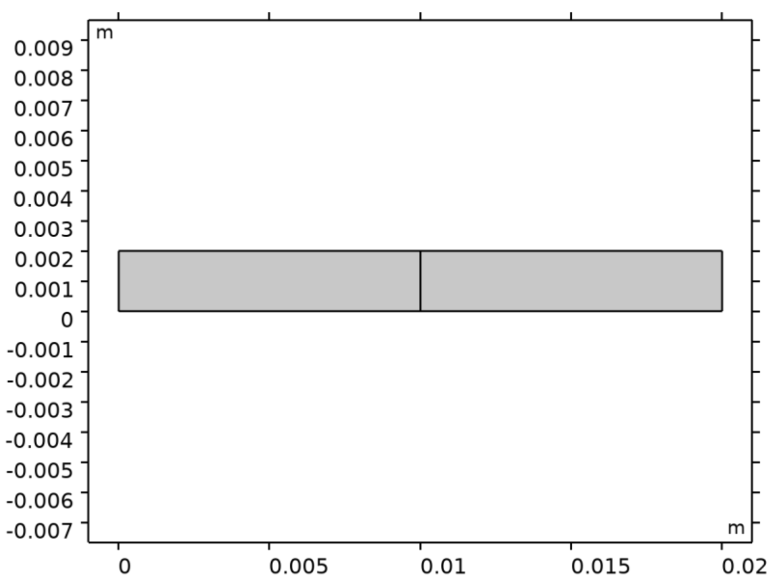
Boundary System 1

Coordinate system type	Boundary system
Tag	sys1

COORDINATE NAMES

First	Second	Third
t1	n	to

2.2 GEOMETRY 1



Geometry 1

UNITS

Length unit	m
Angular unit	deg

GEOMETRY STATISTICS

Description	Value

Description	Value
Space dimension	2
Number of domains	2
Number of boundaries	7
Number of vertices	6

2.2.1 Air (r1)

SIZE AND SHAPE

Description	Value
Width	W
Height	H

POSITION

Description	Value
Position	{0, 0}

2.2.2 Wood (r2)

SIZE AND SHAPE

Description	Value
Width	W
Height	H

POSITION

Description	Value
Position	{W, 0}

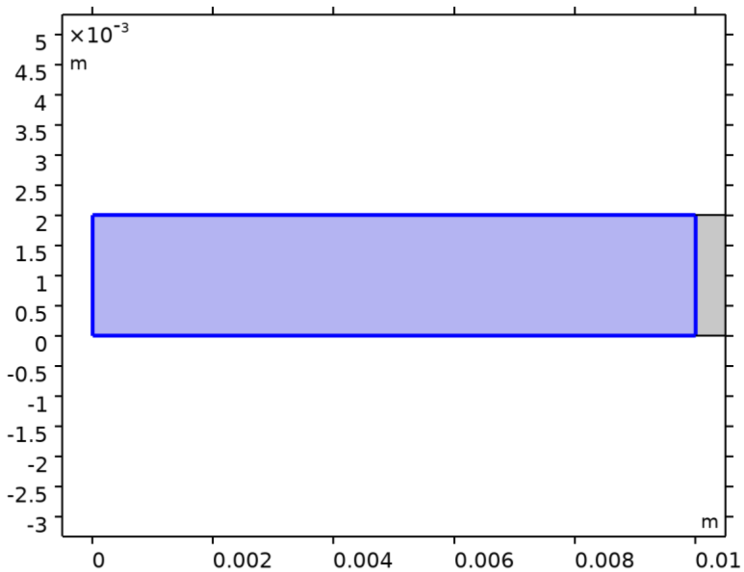
2.2.3 Form Union (fin)

INFORMATION

Description	Value
Build message	Formed union of 2 solid objects. Union has 2 domains, 7 boundaries, and 6 vertices.

2.3 MATERIALS

2.3.1 Water



Water

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domain 1

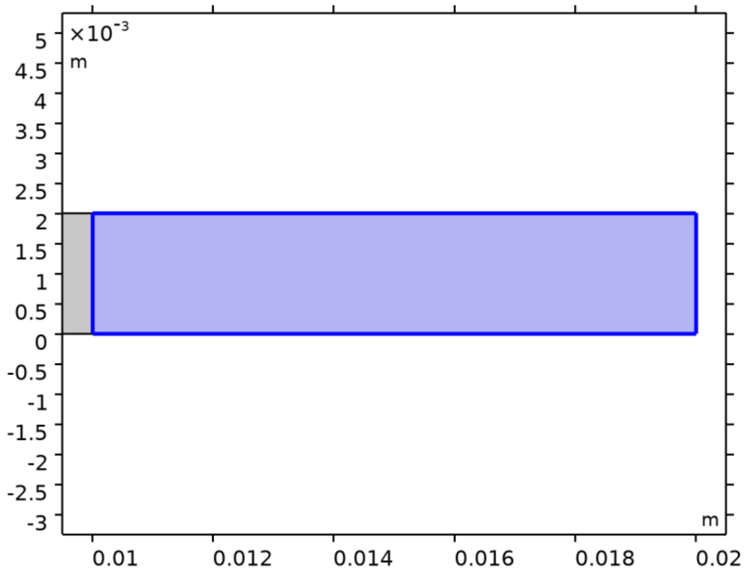
MATERIAL PARAMETERS

Name	Value	Unit	Property group
Density	rw	kg/m^3	Basic
Speed of sound	cw	m/s	Basic

BASIC

Description	Value	Unit
Density	rw	kg/m^3
Speed of sound	cw	m/s

2.3.2 Aluminum



Aluminum

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domain 2

MATERIAL PARAMETERS

Name	**Value**	**Unit**	**Property group**
Density	ra	kg/m^3	Basic
Speed of sound	ca	m/s	Basic

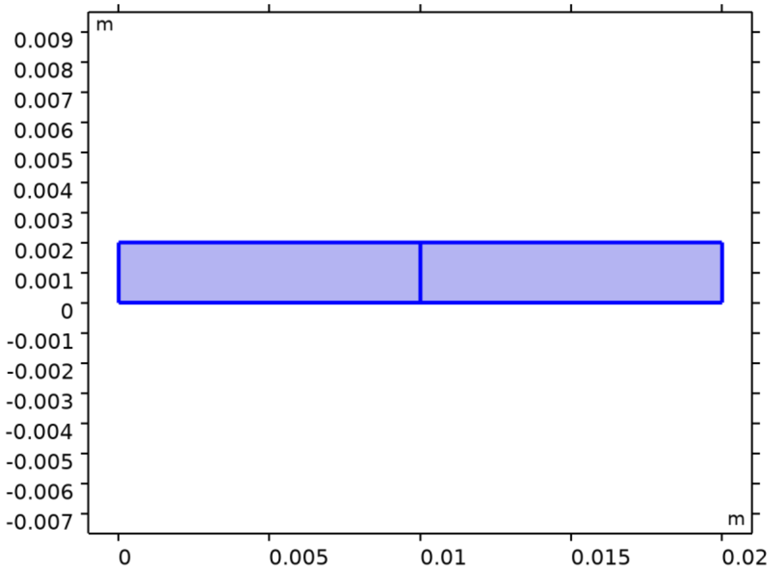
BASIC

Description	**Value**	**Unit**
Density	ra	kg/m^3
Speed of sound	ca	m/s

2.4 PRESSURE ACOUSTICS, FREQUENCY DOMAIN

USED PRODUCTS

COMSOL Multiphysics
Acoustics Module



Pressure Acoustics, Frequency Domain

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: All domains

EQUATIONS

$$\nabla\cdot\left(-\frac{1}{\rho_c}(\nabla p_t-\mathbf{q}_d)\right)-\frac{k_{eq}^2 p_t}{\rho_c}=Q_m$$
$$p_t=p+p_b$$
$$k_{eq}^2=\left(\frac{\omega}{c_c}\right)^2-k_z^2$$

2.4.1 Interface Settings

Physics Symbols

SETTINGS

Description	**Value**
Enable physics symbols	On

Discretization

SETTINGS

Description	**Value**
Element order	Quadratic Lagrange

Physics-Controlled Mesh

SETTINGS

Description	Value
Maximum mesh element size control parameter	From study
Number of mesh elements per wavelength	Automatic

Pressure Acoustics Equation Settings

SETTINGS

Description	Value	Unit
Out-of-plane wave number	0	rad/m

Global Port Settings

SETTINGS

Description	Value
Port sweep settings	No port sweep
Mode shape normalization	Amplitude normalization

Sound Pressure Level Settings

SETTINGS

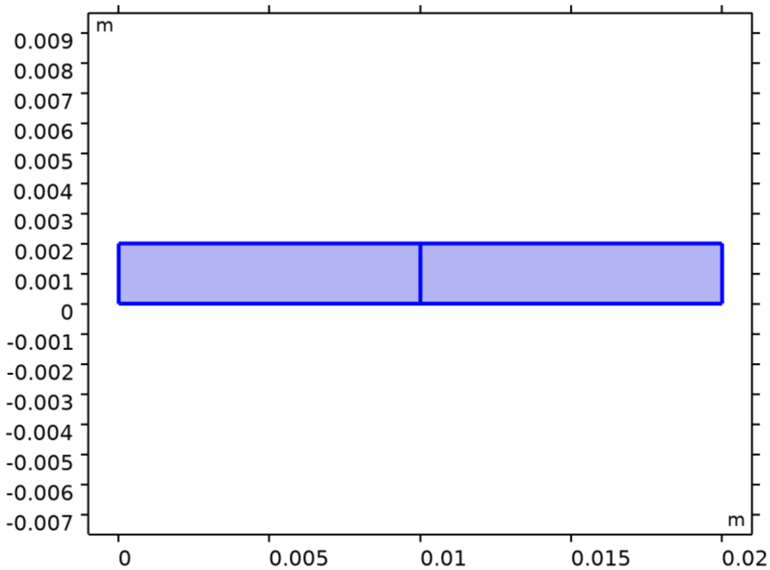
Description	Value
Reference pressure for the sound pressure level	Use reference pressure for air

Typical Wave Speed for Perfectly Matched Layers

SETTINGS

Description	Value	Unit
Typical wave speed for perfectly matched layers	real(acpr.c_c)	m/s

2.4.2 Pressure Acoustics 1



Pressure Acoustics 1

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: All domains

EQUATIONS

$$\nabla \cdot \left(-\frac{1}{\rho_c} (\nabla p_t - \mathbf{q}_d) \right) - \frac{k_{eq}^2 p_t}{\rho_c} = Q_m$$

$$p_t = p + p_b$$

$$k_{eq}^2 = \left(\frac{\omega}{c_c} \right)^2 - k_z^2$$

$$c_c = c, \quad \rho_c = \rho$$

Pressure Acoustics Model

SETTINGS

Description	Value
Fluid model	Linear elastic
Specify	Density and speed of sound
Speed of sound	From material
Density	From material

Model Input

SETTINGS

Description	Value	Unit
Temperature	User defined	
Temperature	293.15	K
Absolute pressure	User defined	
Absolute pressure	1.0133E5	Pa

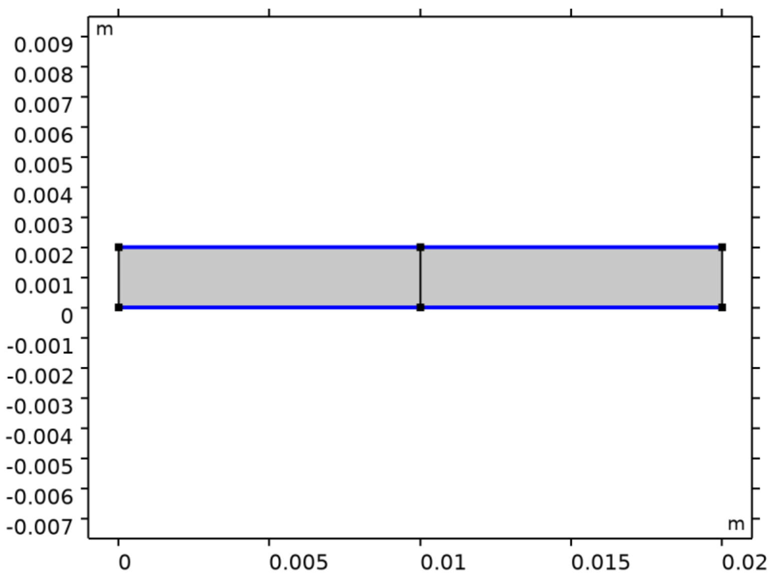
USED PRODUCTS

COMSOL Multiphysics

PROPERTIES FROM MATERIAL

Property	Material	Property group
Density	Water	Basic
Speed of sound	Water	Basic
Density	Aluminum	Basic
Speed of sound	Aluminum	Basic

2.4.3 Sound Hard Boundary (Wall) 1



Sound Hard Boundary (Wall) 1

SELECTION

Geometric entity level	Boundary
Selection	Geometry geom1: Dimension 1: All boundaries

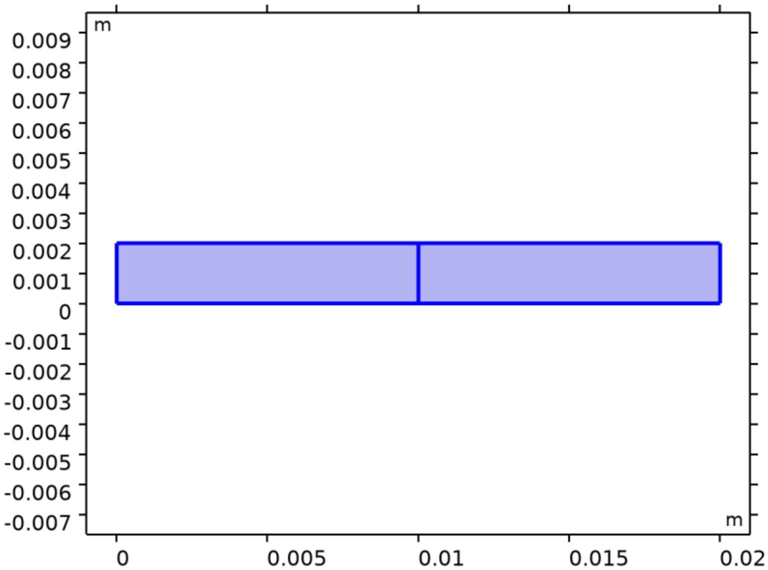
EQUATIONS

$$-\mathbf{n}\cdot\left(-\frac{1}{\rho_c}(\nabla p_t-\mathbf{q}_d)\right)=0$$

USED PRODUCTS

COMSOL Multiphysics

2.4.4 Initial Values 1



Initial Values 1

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: All domains

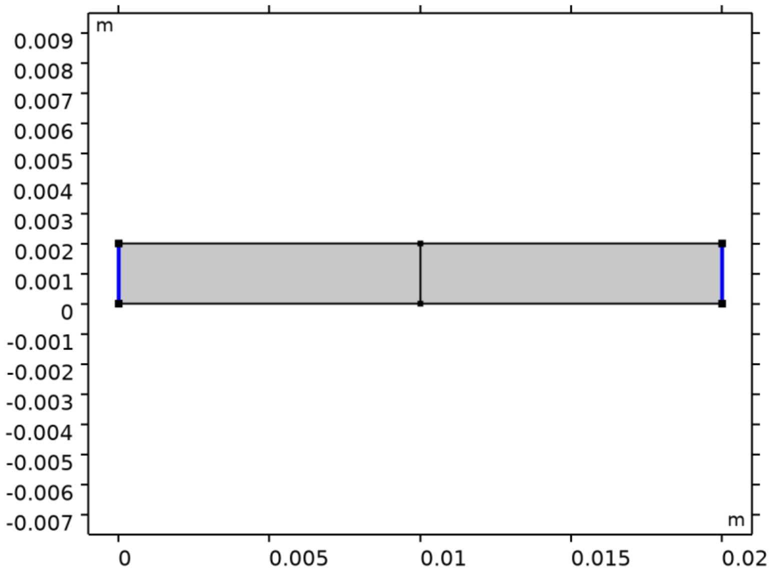
SETTINGS

Description	**Value**	**Unit**
Acoustic pressure	0	Pa

USED PRODUCTS

COMSOL Multiphysics

2.4.5 Plane Wave Radiation 1



Plane Wave Radiation 1

SELECTION

Geometric entity level	Boundary
Selection	Geometry geom1: Dimension 1: Boundaries 1, 7

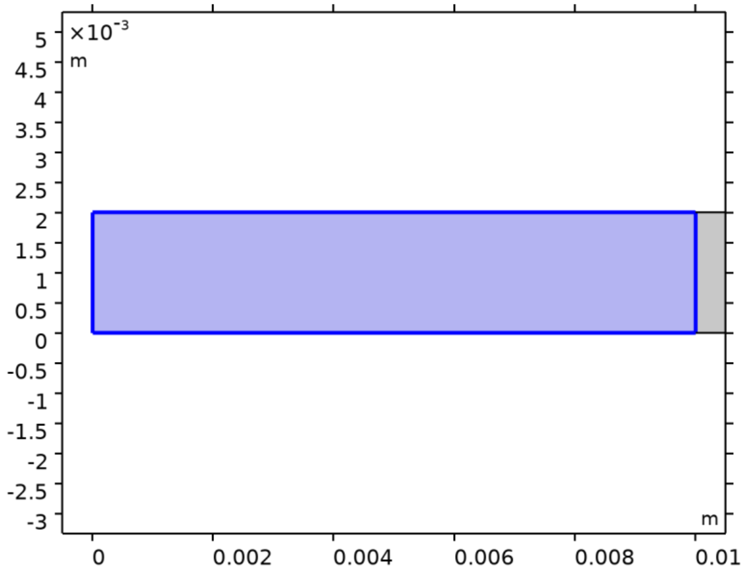
EQUATIONS

$$-\mathbf{n}\cdot\left(-\frac{1}{\rho_c}(\nabla p_t-\mathbf{q}_d)\right)+i\frac{k_{eq}}{\rho_c}p+\frac{i}{2k_{eq}\rho_c}\Delta_{\parallel}p\ =Q_i$$

USED PRODUCTS

COMSOL Multiphysics

2.4.6 Background Pressure Field 1



Background Pressure Field 1

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domain 1

EQUATIONS

$$\nabla\cdot\left(-\frac{1}{\rho_c}(\nabla p_t-\mathbf{q}_d)\right)-\frac{k_{eq}^2 p_t}{\rho_c}=Q_m$$
$$p_t=p+p_b$$
$$k_{eq}^2=\left(\frac{\omega}{c_c}\right)^2-k_z^2$$
$$p_b=p_0 e^{i\phi}e^{-ik_s\frac{(\mathbf{x}\cdot\mathbf{e}_k)}{|\mathbf{e}_k|}}$$
$$k_s^2=\left(\frac{\omega}{c}\right)^2-k_z^2$$

Background Pressure Field

SETTINGS

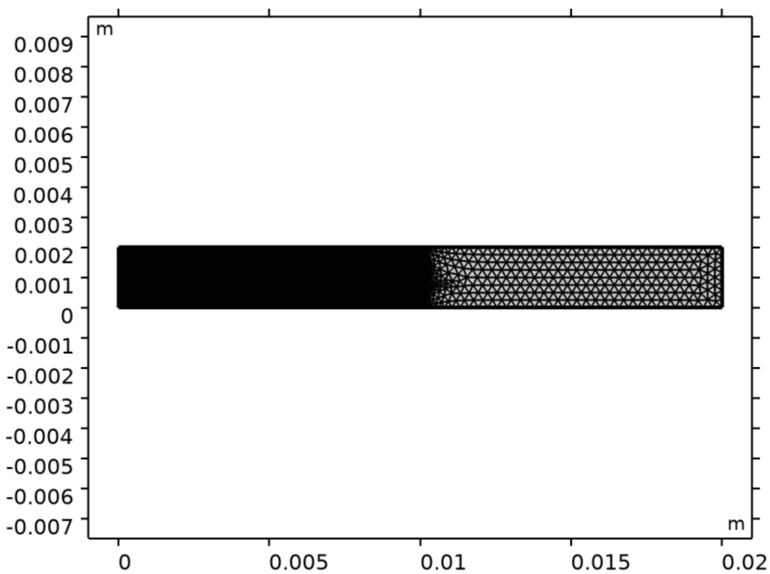
Description	Value	Unit
Pressure field type	Plane wave	
Pressure amplitude	pin	Pa
Speed of sound	From material	
Wave direction, x-component	1	
Wave direction, y-component	0	

Description	Value	Unit
Wave direction, z-component	0	
Phase	0	rad
Calculate background and scattered field intensity	Off	
Material	Domain material	

PROPERTIES FROM MATERIAL

Property	Material	Property group
Speed of sound	Water	Basic

2.5 MESH 1



Mesh 1

2.5.1 Size (size)

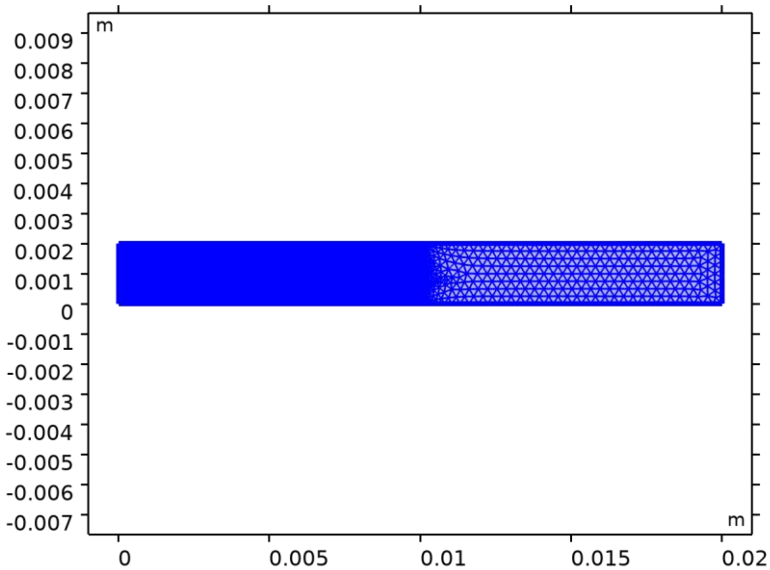
SETTINGS

Description	Value
Maximum element size	4E-4
Minimum element size	2E-7
Curvature factor	0.25
Maximum element growth rate	1.2
Predefined size	Extra fine
Custom element size	Custom

2.5.2 Size Expression 1 (se1)

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domains 1–2



Size Expression 1

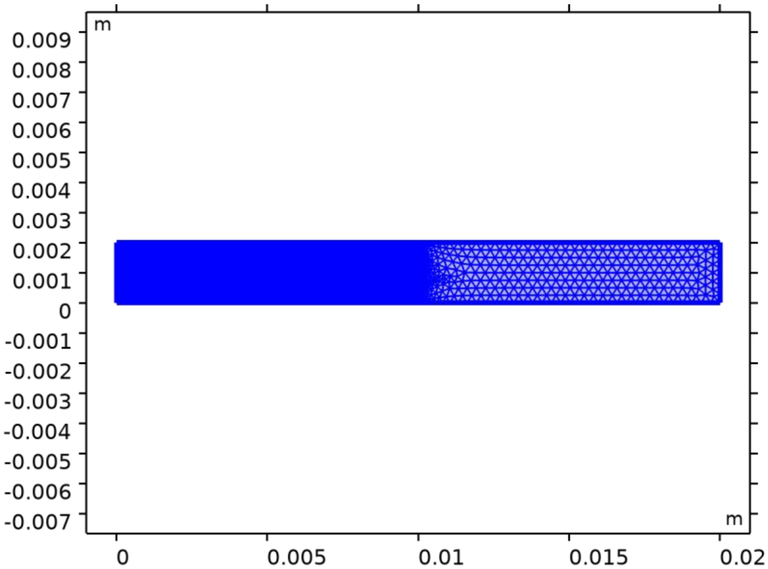
SETTINGS

Description	Value
Evaluate on	Initial expression
Study step	Study 1: Frequency Domain
Size expression	subst(real(acpr.c_c), acpr.freq, freqmax)/freqmax/5
Reevaluate with updated model	

2.5.3 Free Triangular 1 (ftri1)

SELECTION

Geometric entity level	Domain
Selection	Remaining



Free Triangular 1

SETTINGS

Description	Value
Number of iterations	4
Maximum element depth to process	4

INFORMATION

Description	Value
Last build time	< 1 second
Built with	COMSOL 6.3.0.420 (win64), Oct 19, 2025, 5:33:25 PM

3 Study 1

COMPUTATION INFORMATION

Computation time	3 s

3.1 FREQUENCY DOMAIN

Frequencies (Hz)
fin range(100000,100000,4000000)

STUDY SETTINGS

Description	Value
Include geometric nonlinearity	Off

SETTINGS

Description	Value
Frequencies	{2E6, 1E5, 2E5, 3E5, 4E5, 5E5, 6E5, 7E5, 8E5, 9E5, 1E6, 1.1E6, 1.2E6, 1.3E6, 1.4E6, 1.5E6, 1.6E6, 1.7E6, 1.8E6, 1.9E6, 2E6, 2.1E6, 2.2E6, 2.3E6, 2.4E6, 2.5E6, 2.6E6, 2.7E6, 2.8E6, 2.9E6, 3E6, 3.1E6, 3.2E6, 3.3E6, 3.4E6, 3.5E6, 3.6E6, 3.7E6, 3.8E6, 3.9E6, 4E6}

PHYSICS AND VARIABLES SELECTION

Key	Solve for
Pressure Acoustics, Frequency Domain (acpr)	On

STORE IN OUTPUT

Interface	Output	Selection
Pressure Acoustics, Frequency Domain (acpr)	Physics controlled	

MESH SELECTION

Component	Mesh
Component 1	Mesh 1

3.2 SOLVER CONFIGURATIONS

3.2.1 Solution 1

Compile Equations: Frequency Domain (st1)

STUDY AND STEP

Description	Value
Use study	Study 1
Use study step	Frequency Domain

Dependent Variables 1 (v1)

GENERAL

Description	Value
Defined by study step	Step 1: Frequency Domain

INITIAL VALUE CALCULATION CONSTANTS

Constant name	Initial-value source
freq	fin range(100000,100000,4000000)[Hz]

Acoustic Pressure (comp1.p) (comp1_p)

GENERAL

Description	Value
Field components	comp1.p

Stationary Solver 1 (s1)

GENERAL

Description	Value
Defined by study step	Step 1: Frequency Domain

RESULTS WHILE SOLVING

Description	Value
Probes	None

Advanced (aDef)

ASSEMBLY SETTINGS

Description	Value
Reuse sparsity pattern	On
Allow complex-valued output from functions with real input	On

Parametric 1 (p1)

GENERAL

Description	Value
Defined by study step	Step 1: Frequency Domain
Run continuation for	No parameter

PARAMETERS

Parameter name	Parameter value list	Parameter unit
freq	fin range(100000,100000,4000000)	Hz

Fully Coupled 1 (fc1)

GENERAL

Description	Value
Linear solver	Direct

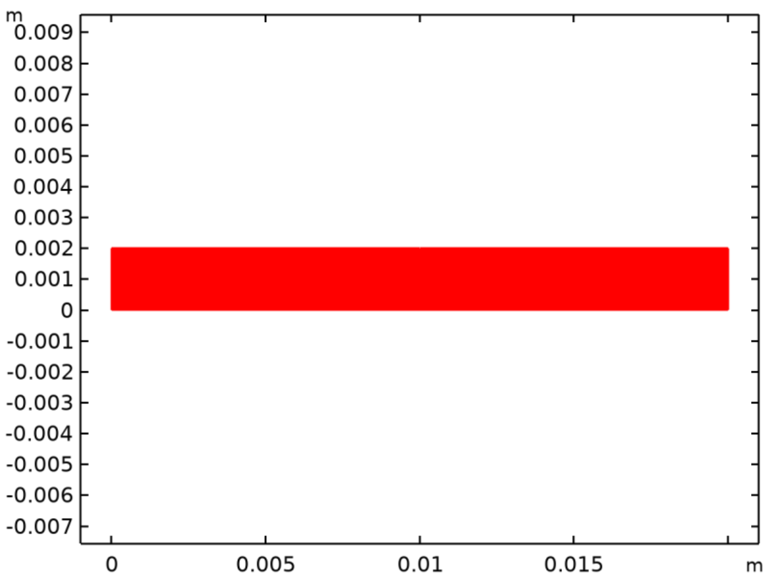
4 Results

4.1 DATASETS

4.1.1 Study 1/Solution 1

SOLUTION

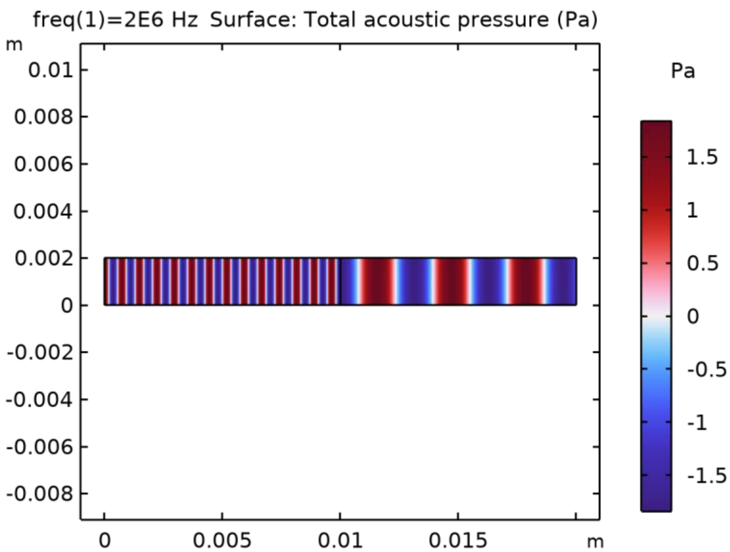
Description	Value
Solution	Solution 1 (sol1)
Component	Component 1 (comp1)



Dataset: Study 1/Solution 1

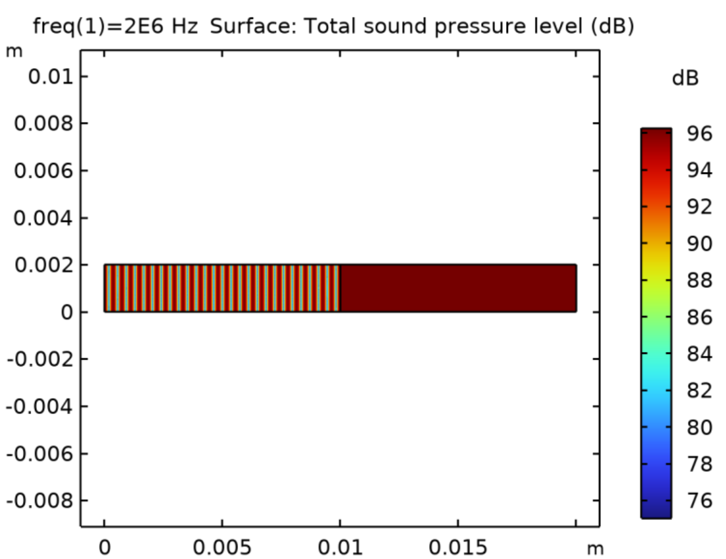
4.2 PLOT GROUPS

4.2.1 Acoustic Pressure (acpr)



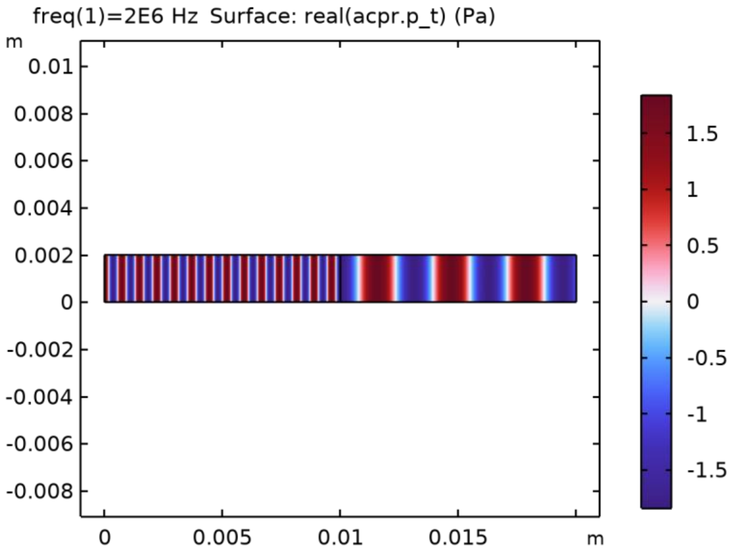
Surface: Total acoustic pressure (Pa)

4.2.2 Sound Pressure Level (acpr)



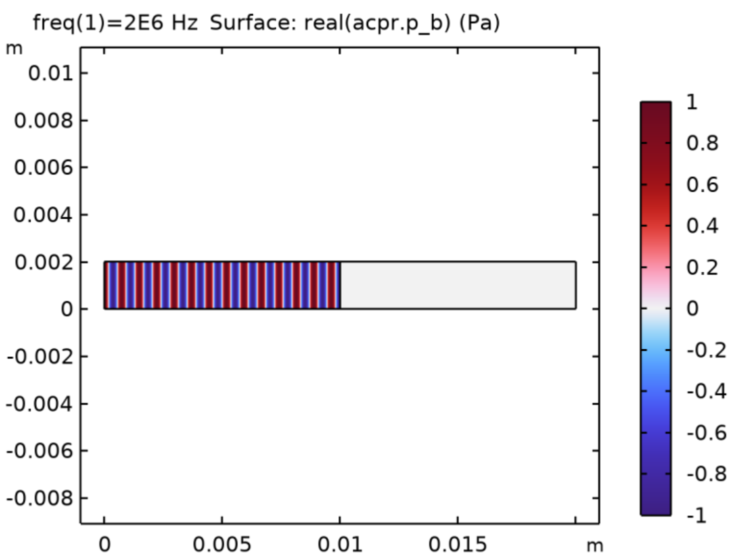
Surface: Total sound pressure level (dB)

4.2.3 2D Plot Group 3



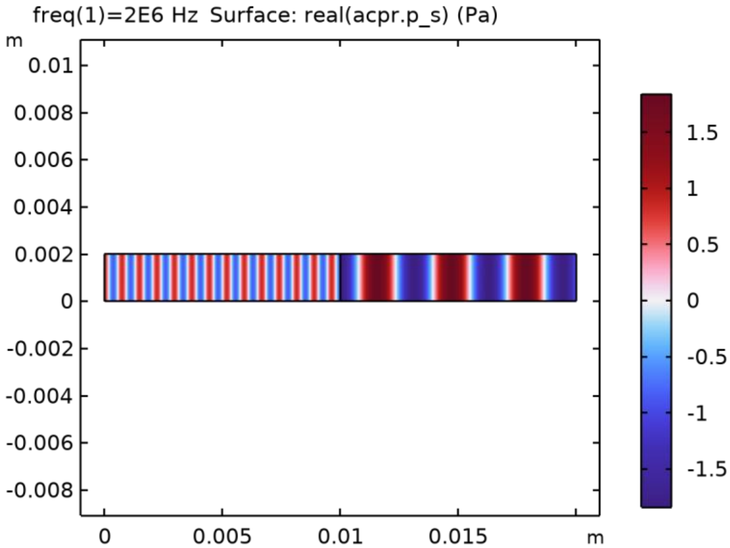
Surface: real(acpr.p_t) (Pa)

4.2.4 2D Plot Group 4



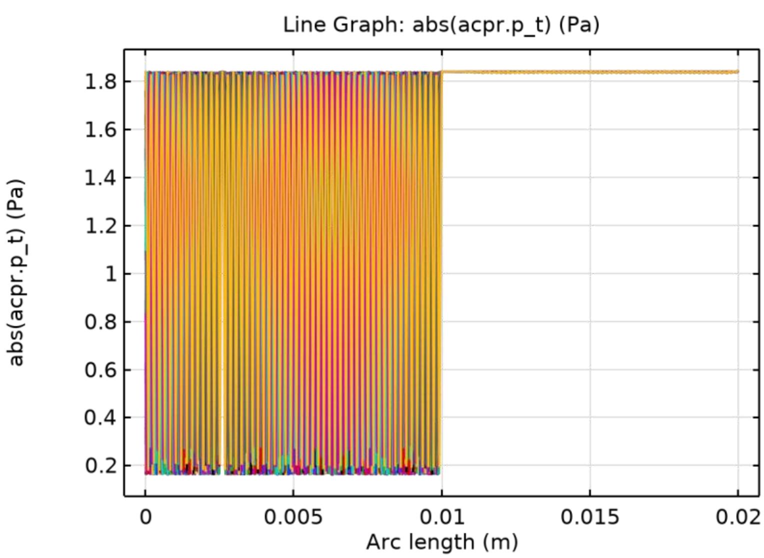
Surface: real(acpr.p_b) (Pa)

4.2.5 2D Plot Group 5



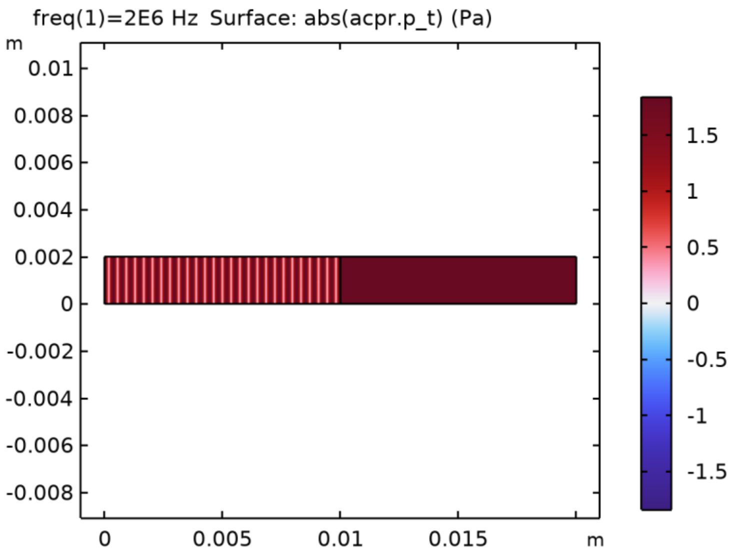
Surface: real(acpr.p_s) (Pa)

4.2.6 1D Plot Group 6



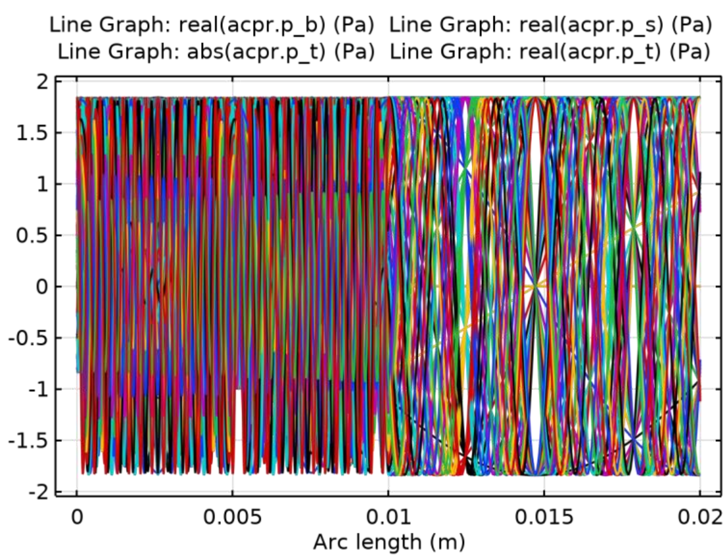
Line Graph: abs(acpr.p_t) (Pa)

4.2.7 2D Plot Group 7



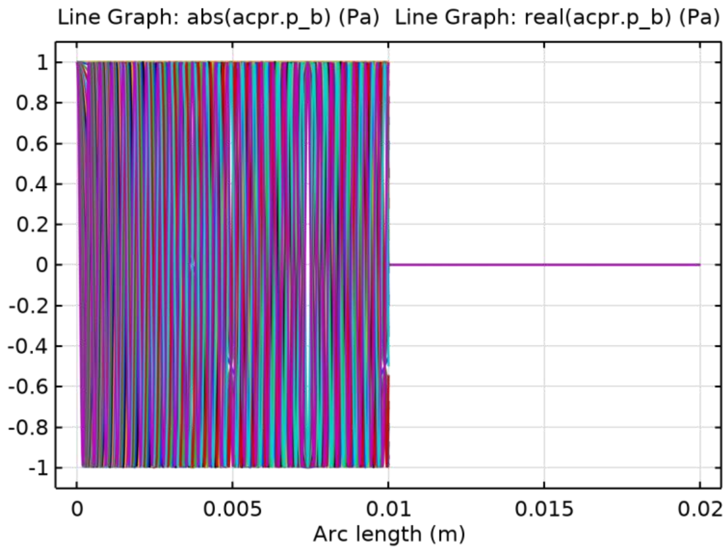
Surface: abs(acpr.p_t) (Pa)

4.2.8 1D Plot Group 8



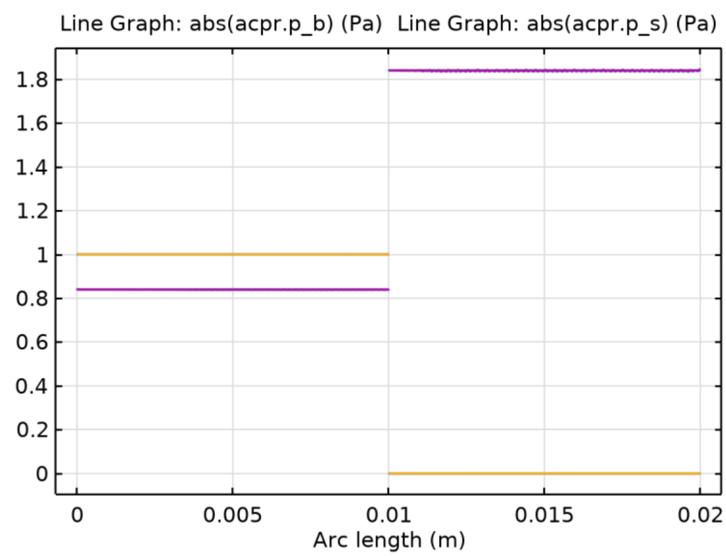
Line Graph: real(acpr.p_b) (Pa) Line Graph: real(acpr.p_s) (Pa) Line Graph: abs(acpr.p_t) (Pa) Line Graph: real(acpr.p_t) (Pa)

4.2.9 1D Plot Group 9



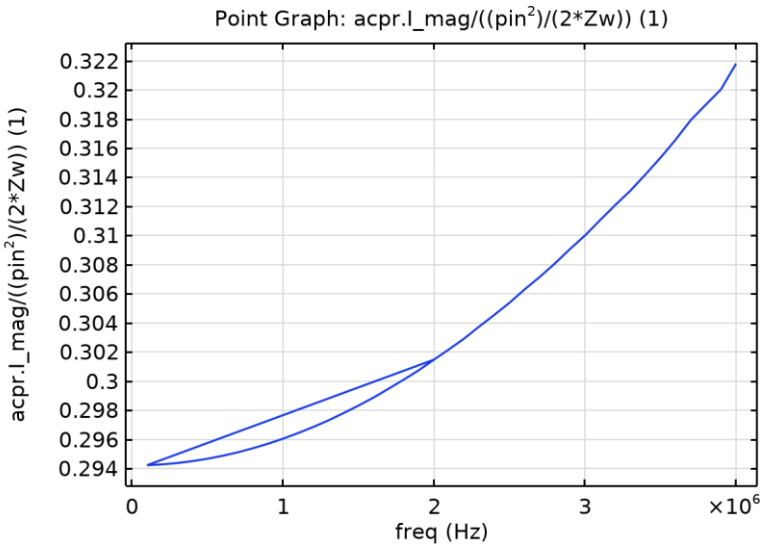
Line Graph: abs(acpr.p_b) (Pa) Line Graph: real(acpr.p_b) (Pa)

4.2.10 1D Plot Group 10



Line Graph: abs(acpr.p_b) (Pa) Line Graph: abs(acpr.p_s) (Pa)

4.2.11 1D Plot Group 11



*Point Graph: acpr.I_mag/((pin^2)/(2*Zw)) (1)*

Hw3.2

Report date	Oct 19, 2025, 6:00:27 PM

Contents

1 Global Definitions

Date	Oct 19, 2025, 5:51:59 PM

GLOBAL SETTINGS

Name	Hw3.2.mph
Path	\\clusterfsnew.ceas1.uc.edu\students\brooksl\desktop\hw3.2.mph
Version	COMSOL Multiphysics 6.3 (Build: 420)

USED PRODUCTS

COMSOL Multiphysics
Acoustics Module

COMPUTER INFORMATION

CPU	Intel64 Family 6 Model 198 Stepping 2, 28 cores, 63.46 GB RAM
Operating system	Windows 11

1.1 PARAMETERS

PARAMETERS 1

Name	Expression	Value	Description
ra	2700[kg/m^3]	2700 kg/m³	
ca	6300[m/s]	6300 m/s	
rw	998[kg/m^3]	998 kg/m³	
cw	1481[m/s]	1481 m/s	
pin	1[Pa]	1 Pa	
fin	2[MHz]	2E6 Hz	
W	1[cm]	0.01 m	
H	2[mm]	0.002 m	
Zw	rw*cw	1.478E6 kg/(m²·s)	
Za	ra*ca	1.701E7 kg/(m²·s)	
R	(Za - Zw)/(Zw + Za)	0.84011	
T	(2*Za)/(Zw + Za)	1.8401	
Ri	((Za - Zw)/(Zw + Za))^2	0.70578	
Ti	4*Za*Zw/(Zw + Za)^2	0.29422	
cL	sqrt(cw*ca)	3054.6 m/s	
L	cL/(4*fin)	3.8182E−4 m	
rL	sqrt(rw*ra)	1641.5 kg/m³	

2 Component 1

SETTINGS

Description	Value
Unit system	Same as global system (SI)

2.1 DEFINITIONS

2.1.1 Coordinate Systems

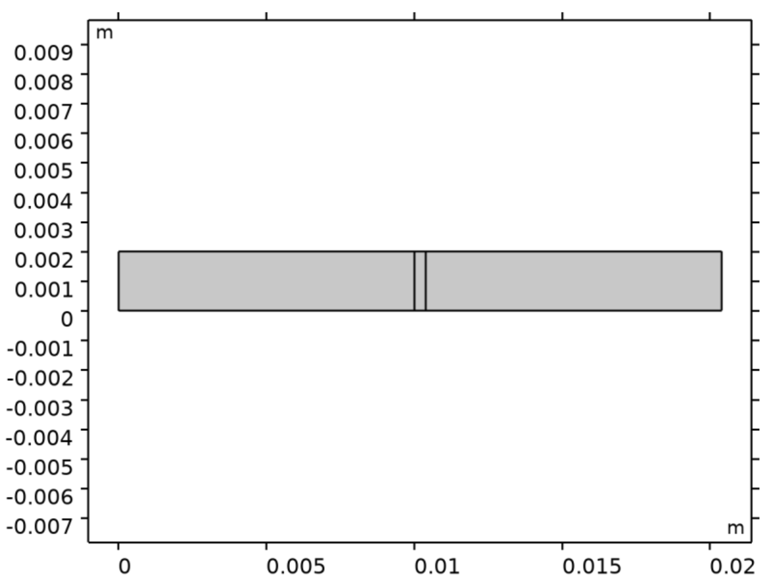
Boundary System 1

Coordinate system type	Boundary system
Tag	sys1

COORDINATE NAMES

First	Second	Third
t1	n	to

2.2 GEOMETRY 1



Geometry 1

UNITS

Length unit	m
Angular unit	deg

GEOMETRY STATISTICS

Description	Value

Description	Value
Space dimension	2
Number of domains	3
Number of boundaries	10
Number of vertices	8

2.2.1 Air (r1)

SIZE AND SHAPE

Description	Value
Width	W
Height	H

POSITION

Description	Value
Position	{0, 0}

2.2.2 Wood (r2)

SIZE AND SHAPE

Description	Value
Width	W
Height	H

POSITION

Description	Value
Position	{W + L, 0}

2.2.3 Rectangle 3 (r3)

SIZE AND SHAPE

Description	Value
Width	L
Height	H

POSITION

Description	Value
Position	{W, 0}

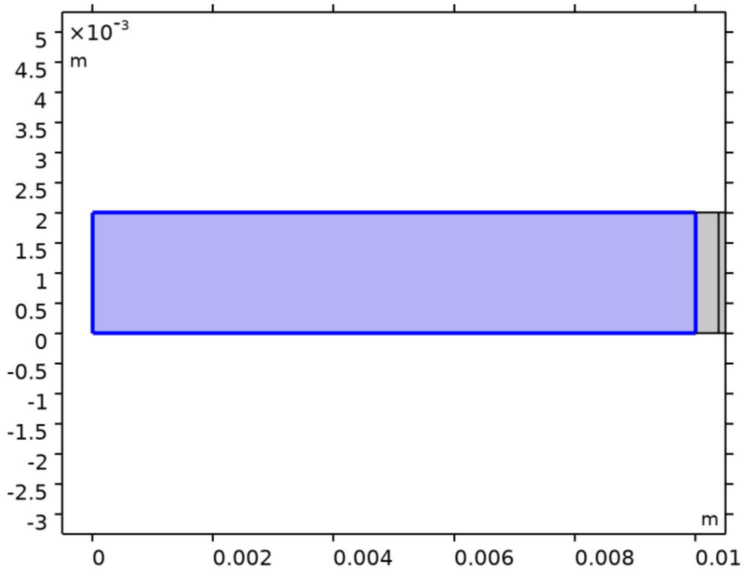
2.2.4 Form Union (fin)

INFORMATION

Description	Value
Build message	Formed union of 3 solid objects. Union has 3 domains, 10 boundaries, and 8 vertices.

2.3 MATERIALS

2.3.1 Water



Water

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domain 1

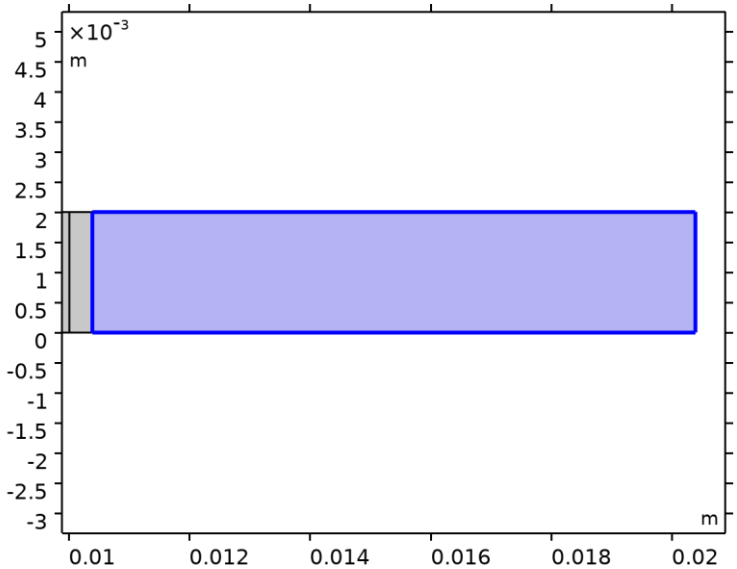
MATERIAL PARAMETERS

Name	Value	Unit	Property group
Density	rw	kg/m^3	Basic
Speed of sound	cw	m/s	Basic

BASIC

Description	Value	Unit
Density	rw	kg/m^3
Speed of sound	cw	m/s

2.3.2 Aluminum



Aluminum

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domain 3

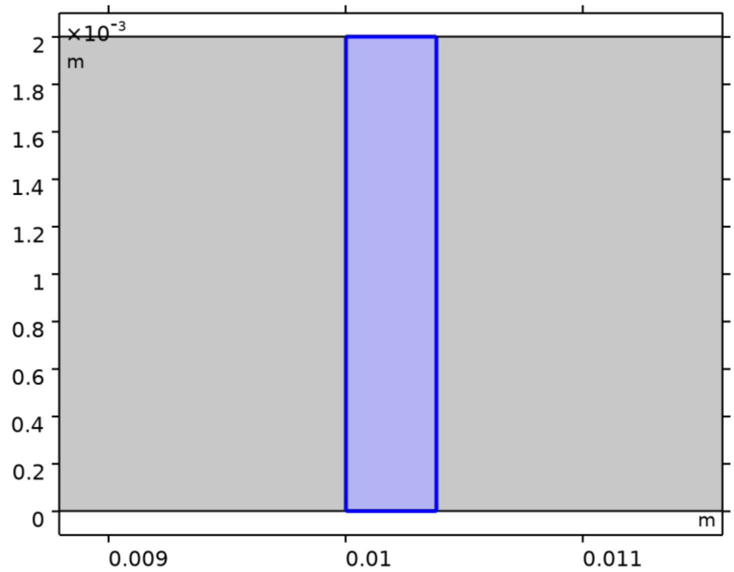
MATERIAL PARAMETERS

Name	Value	Unit	Property group
Density	ra	kg/m³	Basic
Speed of sound	ca	m/s	Basic

BASIC

Description	Value	Unit
Density	ra	kg/m³
Speed of sound	ca	m/s

2.3.3 Layer



Layer

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domain 2

MATERIAL PARAMETERS

Name	Value	Unit	Property group
Density	rL	kg/m³	Basic
Speed of sound	cL	m/s	Basic

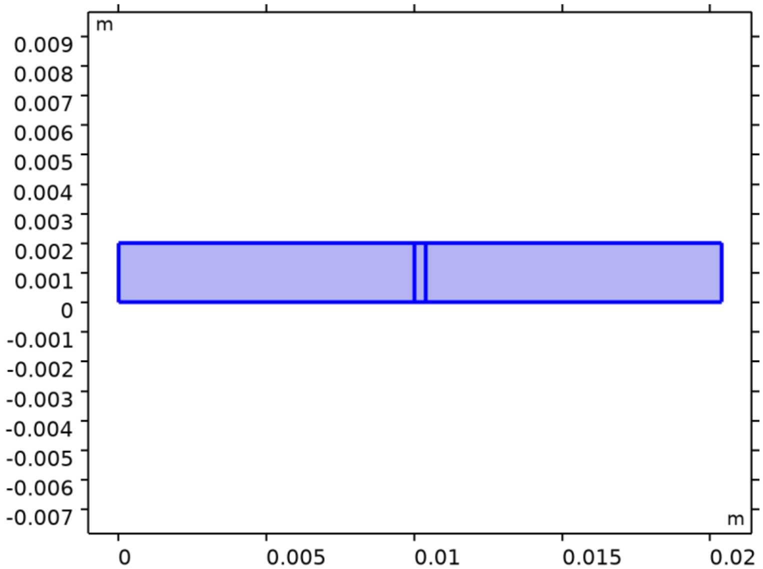
BASIC

Description	Value	Unit
Density	rL	kg/m³
Speed of sound	cL	m/s

2.4 PRESSURE ACOUSTICS, FREQUENCY DOMAIN

USED PRODUCTS

COMSOL Multiphysics
Acoustics Module



Pressure Acoustics, Frequency Domain

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: All domains

EQUATIONS

$$\nabla\cdot\left(-\frac{1}{\rho_c}(\nabla p_t-\mathbf{q}_d)\right)-\frac{k_{eq}^2 p_t}{\rho_c}=Q_m$$

$$p_t=p+p_b$$

$$k_{eq}^2=\left(\frac{\omega}{c_c}\right)^2-k_z^2$$

2.4.1 Interface Settings

Physics Symbols

SETTINGS

Description	Value
Enable physics symbols	On

Discretization

SETTINGS

Description	Value
Element order	Quadratic Lagrange

Physics-Controlled Mesh

SETTINGS

Description	Value
Maximum mesh element size control parameter	From study
Number of mesh elements per wavelength	Automatic

Pressure Acoustics Equation Settings

SETTINGS

Description	Value	Unit
Out-of-plane wave number	0	rad/m

Global Port Settings

SETTINGS

Description	Value
Port sweep settings	No port sweep
Mode shape normalization	Amplitude normalization

Sound Pressure Level Settings

SETTINGS

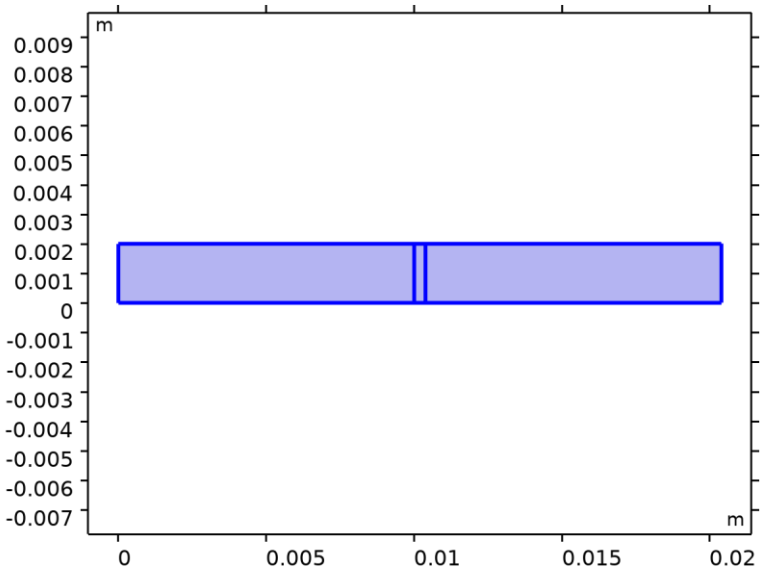
Description	Value
Reference pressure for the sound pressure level	Use reference pressure for air

Typical Wave Speed for Perfectly Matched Layers

SETTINGS

Description	Value	Unit
Typical wave speed for perfectly matched layers	real(acpr.c_c)	m/s

2.4.2 Pressure Acoustics 1



Pressure Acoustics 1

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: All domains

EQUATIONS

$$\nabla\cdot\left(-\frac{1}{\rho_c}(\nabla p_t-\mathbf{q}_d)\right)-\frac{k_{eq}^2 p_t}{\rho_c}=Q_m$$

$$p_t=p+p_b$$

$$k_{eq}^2=\left(\frac{\omega}{c_c}\right)^2-k_z^2$$

$$c_c=c,\quad \rho_c=\rho$$

Pressure Acoustics Model

SETTINGS

Description	Value
Fluid model	Linear elastic
Specify	Density and speed of sound
Speed of sound	From material
Density	From material

Model Input

SETTINGS

Description	Value	Unit
Temperature	User defined	
Temperature	293.15	K
Absolute pressure	User defined	
Absolute pressure	1.0133E5	Pa

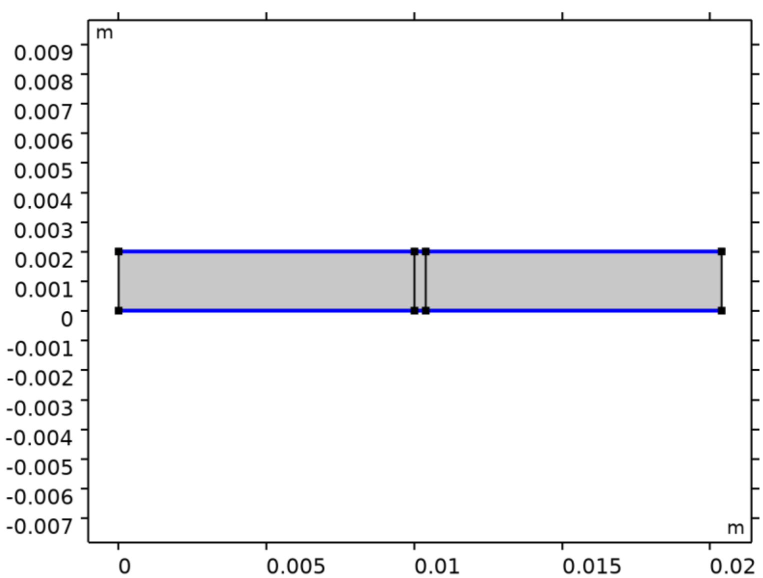
USED PRODUCTS

COMSOL Multiphysics

PROPERTIES FROM MATERIAL

Property	Material	Property group
Density	Water	Basic
Speed of sound	Water	Basic
Density	Aluminum	Basic
Speed of sound	Aluminum	Basic
Density	Layer	Basic
Speed of sound	Layer	Basic

2.4.3 Sound Hard Boundary (Wall) 1



Sound Hard Boundary (Wall) 1

SELECTION

Geometric entity level	Boundary
Selection	Geometry geom1: Dimension 1: All boundaries

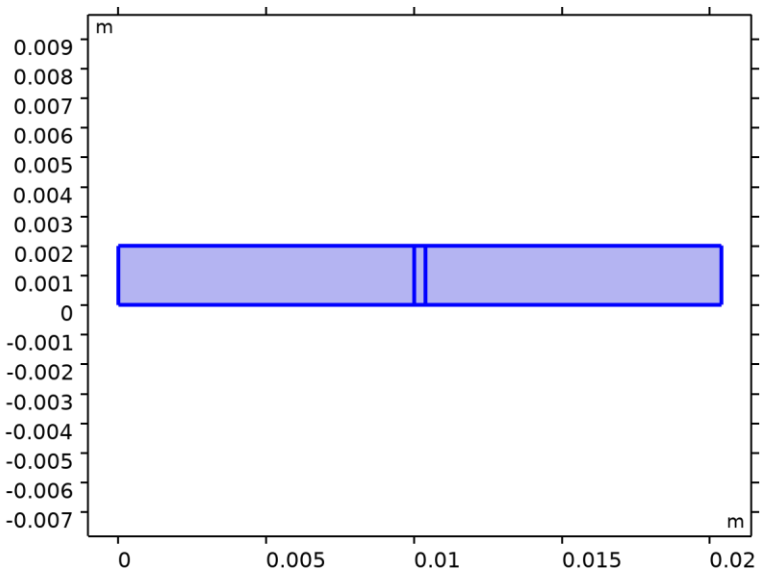
EQUATIONS

$$-\mathbf{n}\cdot\left(-\frac{1}{\rho_c}(\nabla p_t-\mathbf{q}_d)\right)=0$$

USED PRODUCTS

COMSOL Multiphysics

2.4.4 Initial Values 1



Initial Values 1

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: All domains

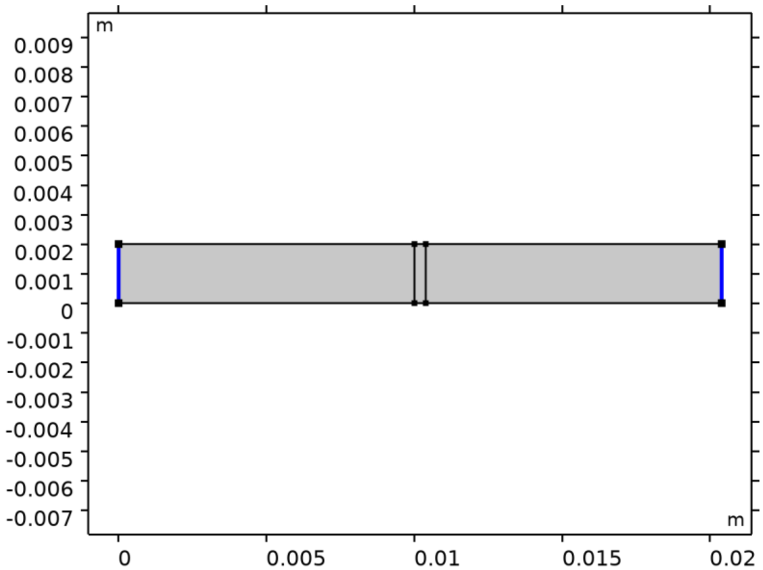
SETTINGS

Description	**Value**	**Unit**
Acoustic pressure	0	Pa

USED PRODUCTS

COMSOL Multiphysics

2.4.5 Plane Wave Radiation 1



Plane Wave Radiation 1

SELECTION

Geometric entity level	Boundary
Selection	Geometry geom1: Dimension 1: Boundaries 1, 10

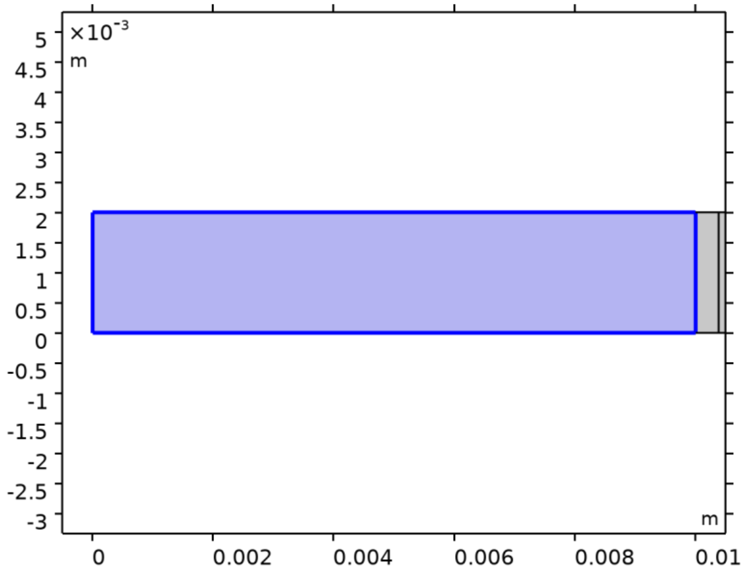
EQUATIONS

$$-\mathbf{n}\cdot\left(-\frac{1}{\rho_c}(\nabla p_t-\mathbf{q}_d)\right)+i\frac{k_{eq}}{\rho_c}p+\frac{i}{2k_{eq}\rho_c}\Delta_{\parallel}p\ =Q_i$$

USED PRODUCTS

COMSOL Multiphysics

2.4.6 Background Pressure Field 1



Background Pressure Field 1

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domain 1

EQUATIONS

$$\nabla \cdot \left(-\frac{1}{\rho_c}(\nabla p_t - \mathbf{q}_d)\right) - \frac{k_{eq}^2 p_t}{\rho_c} = Q_m$$
$$p_t = p + p_b$$
$$k_{eq}^2 = \left(\frac{\omega}{c_c}\right)^2 - k_z^2$$
$$p_b = p_0 e^{i\phi} e^{-ik_s \frac{(\mathbf{x} \cdot \mathbf{e}_k)}{|\mathbf{e}_k|}}$$
$$k_s^2 = \left(\frac{\omega}{c}\right)^2 - k_z^2$$

Background Pressure Field

SETTINGS

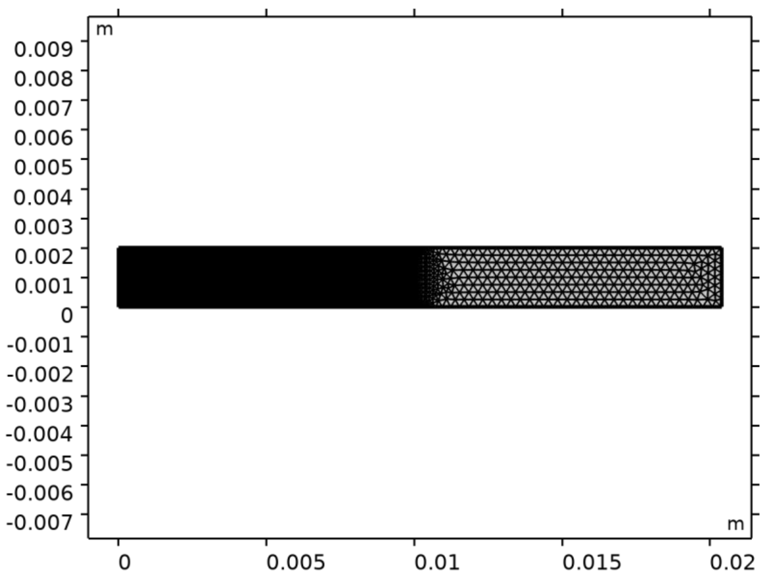
Description	Value	Unit
Pressure field type	Plane wave	
Pressure amplitude	pin	Pa
Speed of sound	From material	
Wave direction, x-component	1	
Wave direction, y-component	0	

Description	Value	Unit
Wave direction, z-component	0	
Phase	0	rad
Calculate background and scattered field intensity	Off	
Material	Domain material	

PROPERTIES FROM MATERIAL

Property	Material	Property group
Speed of sound	Water	Basic

2.5 MESH 1



Mesh 1

2.5.1 Size (size)

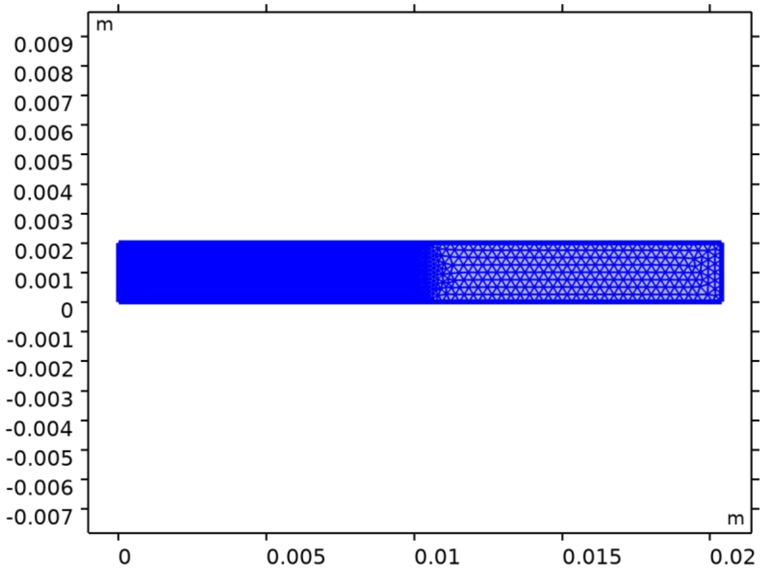
SETTINGS

Description	Value
Maximum element size	4.08E-4
Minimum element size	2.038E-7
Curvature factor	0.25
Maximum element growth rate	1.2
Predefined size	Extra fine
Custom element size	Custom

2.5.2 Size Expression 1 (se1)

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domains 1–3



Size Expression 1

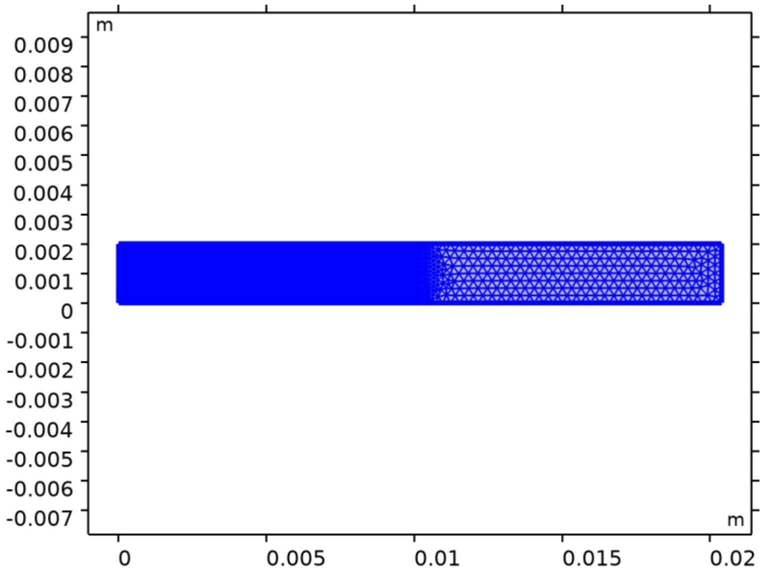
SETTINGS

Description	Value
Evaluate on	Initial expression
Study step	Study 1: Frequency Domain
Size expression	subst(real(acpr.c_c), acpr.freq, freqmax)/freqmax/5
Reevaluate with updated model	

2.5.3 Free Triangular 1 (ftri1)

SELECTION

Geometric entity level	Domain
Selection	Remaining



Free Triangular 1

SETTINGS

Description	Value
Number of iterations	4
Maximum element depth to process	4

INFORMATION

Description	Value
Last build time	< 1 second
Built with	COMSOL 6.3.0.420 (win64), Oct 19, 2025, 5:54:57 PM

3 Study 1

COMPUTATION INFORMATION

Computation time	3 s

3.1 FREQUENCY DOMAIN

Frequencies (Hz)
fin range(100000,100000,4000000)

STUDY SETTINGS

Description	Value
Include geometric nonlinearity	Off

SETTINGS

Description	Value
Frequencies	{2E6, 1E5, 2E5, 3E5, 4E5, 5E5, 6E5, 7E5, 8E5, 9E5, 1E6, 1.1E6, 1.2E6, 1.3E6, 1.4E6, 1.5E6, 1.6E6, 1.7E6, 1.8E6, 1.9E6, 2E6, 2.1E6, 2.2E6, 2.3E6, 2.4E6, 2.5E6, 2.6E6, 2.7E6, 2.8E6, 2.9E6, 3E6, 3.1E6, 3.2E6, 3.3E6, 3.4E6, 3.5E6, 3.6E6, 3.7E6, 3.8E6, 3.9E6, 4E6}

PHYSICS AND VARIABLES SELECTION

Key	Solve for
Pressure Acoustics, Frequency Domain (acpr)	On

STORE IN OUTPUT

Interface	Output	Selection
Pressure Acoustics, Frequency Domain (acpr)	Physics controlled	

MESH SELECTION

Component	Mesh
Component 1	Mesh 1

3.2 SOLVER CONFIGURATIONS

3.2.1 Solution 1

Compile Equations: Frequency Domain (st1)

STUDY AND STEP

Description	Value
Use study	Study 1
Use study step	Frequency Domain

Dependent Variables 1 (v1)

GENERAL

Description	Value
Defined by study step	Step 1: Frequency Domain

INITIAL VALUE CALCULATION CONSTANTS

Constant name	Initial-value source
freq	fin range(100000,100000,4000000)[Hz]

Acoustic Pressure (comp1.p) (comp1_p)

GENERAL

Description	Value
Field components	comp1.p

Stationary Solver 1 (s1)

GENERAL

Description	Value
Defined by study step	Step 1: Frequency Domain

RESULTS WHILE SOLVING

Description	Value
Probes	None

Advanced (aDef)

ASSEMBLY SETTINGS

Description	Value
Reuse sparsity pattern	On
Allow complex-valued output from functions with real input	On

Parametric 1 (p1)

GENERAL

Description	Value
Defined by study step	Step 1: Frequency Domain
Run continuation for	No parameter

PARAMETERS

Parameter name	Parameter value list	Parameter unit
freq	fin range(100000,100000,4000000)	Hz

Fully Coupled 1 (fc1)

GENERAL

Description	Value
Linear solver	Direct

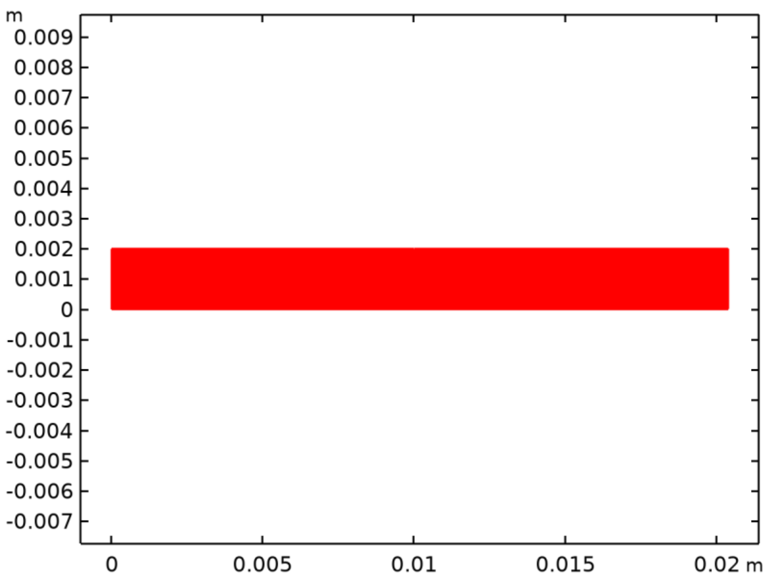
4 Results

4.1 DATASETS

4.1.1 Study 1/Solution 1

SOLUTION

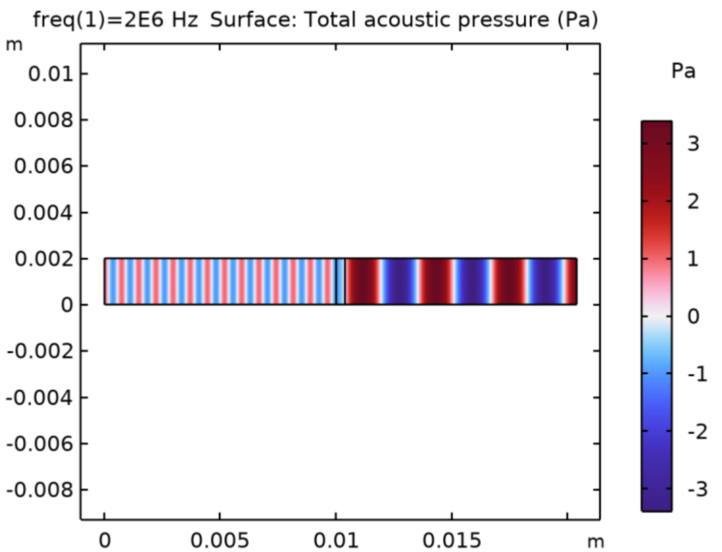
Description	Value
Solution	Solution 1 (sol1)
Component	Component 1 (comp1)



Dataset: Study 1/Solution 1

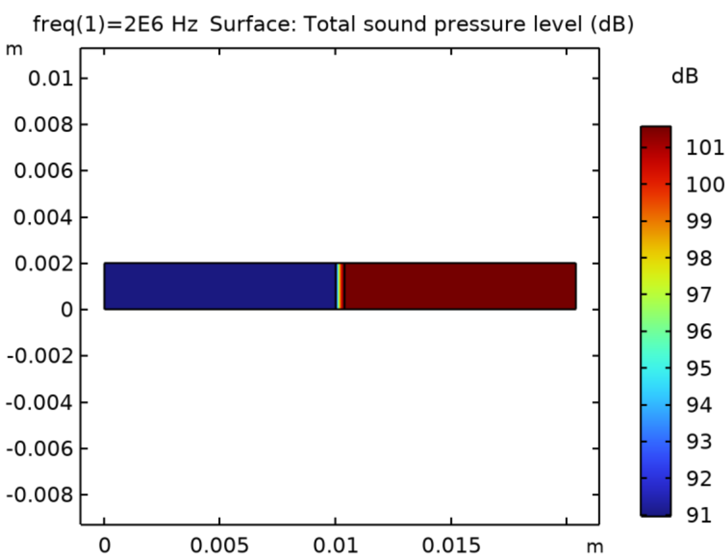
4.2 PLOT GROUPS

4.2.1 Acoustic Pressure (acpr)



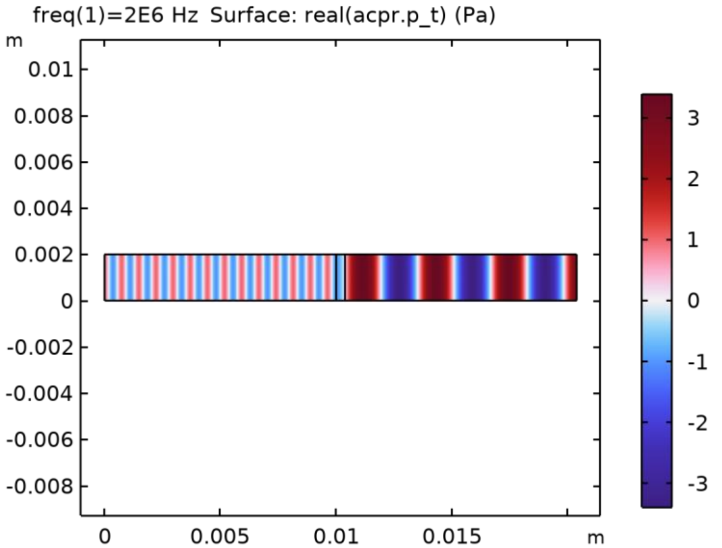
Surface: Total acoustic pressure (Pa)

4.2.2 Sound Pressure Level (acpr)



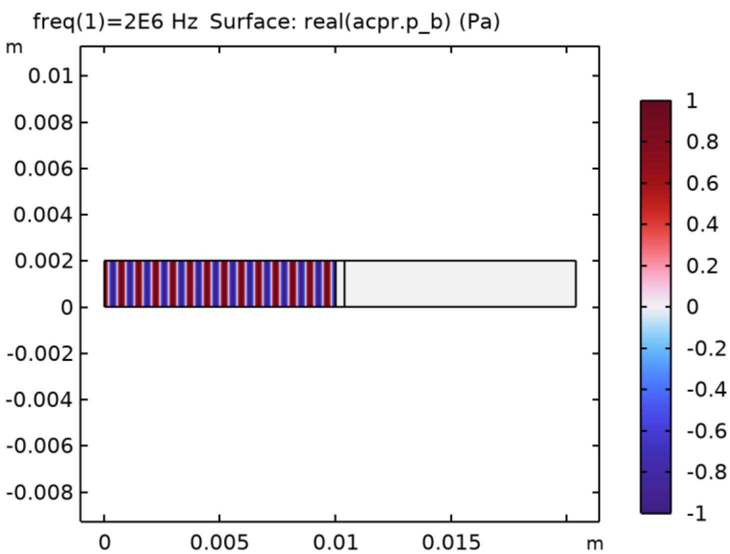
Surface: Total sound pressure level (dB)

4.2.3 2D Plot Group 3



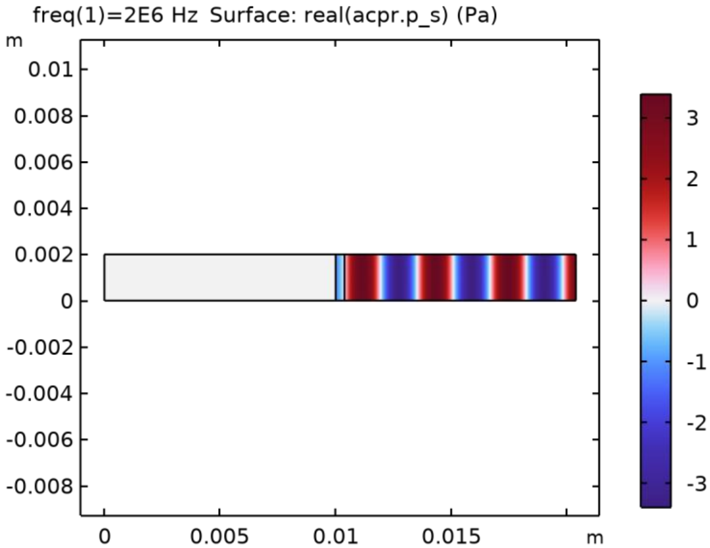
Surface: real(acpr.p_t) (Pa)

4.2.4 2D Plot Group 4



Surface: real(acpr.p_b) (Pa)

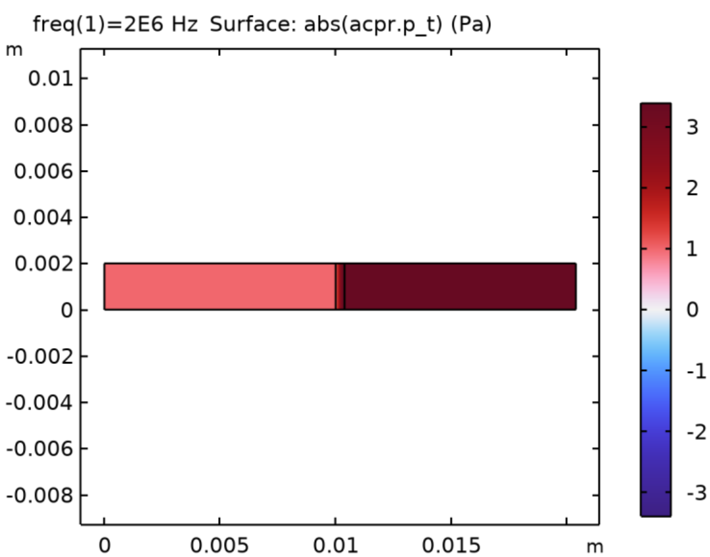
4.2.5 2D Plot Group 5



Surface: real(acpr.p_s) (Pa)

4.2.6 1D Plot Group 6

4.2.7 2D Plot Group 7



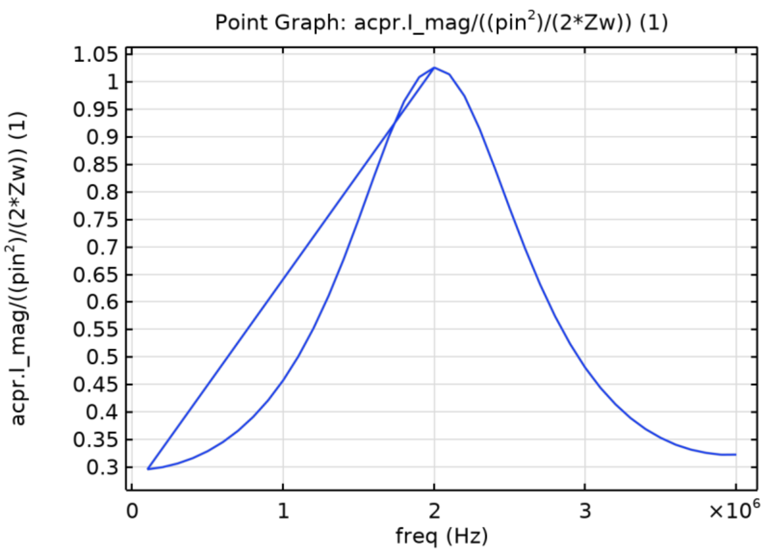
Surface: abs(acpr.p_t) (Pa)

4.2.8 1D Plot Group 8

4.2.9 1D Plot Group 9

4.2.10 1D Plot Group 10

4.2.11 1D Plot Group 11



*Point Graph: acpr.I_mag/((pin^2)/(2*Zw)) (1)*