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Islamic University of Technology

Department of Mechanical and Production Engineering

ANALYSIS OF DIFFERENT METAMATERIALS BASED ON LOW FREQUENCY SOUND TRANSMISSION LOSS USING COMSOL MULTIPHYSICS

A Thesis by
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Submitted in Partial Fulfillment
Of the Requirements
For the Degree of

Bachelor of Science in Mechanical Engineering

May (2022)

CERTIFICATE OF RESEARCH

This thesis titled "ANALYSIS OF DIFFERENT METAMATERIALS BASED ON LOW FREQUENCY SOUND TRANSMISSION LOSS USING COMSOL MULTIPHYSICS" submitted by JUNAYED BIN ZAKIR (170011065) and S. M. MUSTAFIZUR RAHMAN (170011055) has been accepted as satisfactory in partial fulfillment of the requirement for the Degree of Bachelor of Science in Mechanical Engineering.

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DECLARATION

I hereby declare that this thesis entitled "ANALYSIS OF DIFFERENT METAMATERIALS BASED ON LOW FREQUENCY SOUND TRANSMISSION LOSS USING COMSOL MULTIPHYSICS" is an authentic report of our study carried out as requirement for the award of degree B.Sc. (Mechanical Engineering) at Islamic University of Technology, Gazipur, Dhaka, under the supervision of
Mr.Nagib Mehfuz,
Assistant professor, MPE, IUT in the year 2022

The matter embodied in this thesis has not been submitted in part or full to any other institute for
award of any degree.

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Acknowledgement

In the Name of Allah, the Most Beneficent, the Most Merciful

The journey through the completion of this thesis required immense effort from every individual involved. The completion of this thesis would have been far from reality if it were not for the constant support from thesis supervisor who guided us through the entire study. We would like to express our heartfelt gratitude to Mr. Nagib Mehfuz for being our esteemed supervisor and providing his expert insight for setting our goals clearly, as well as building a strong baseline for our thesis. His insightful instructions helped us to envision the results that we had to aim for from the very beginning of our thesis work. Last, but not the least, each of us would like to extend our acknowledgements to our respective parents for being the resilient support during the long sleepless nights of work on this thesis.

ABSTRACT

In this day and age noise reduction is an increasingly relevant and rapidly progressing sector of technology. It is necessary due to the numerous psychological benefits of a relatively quiet atmosphere. In this paper, we will be attempting to identify the best structures to induce maximum reduction of power in a sound wave prior to its transmission through the material. For this, we intend to use a simulation software and test out various permutations of the geometry and the material composition of two preselected metamaterials. Metamaterials are chosen due to their ability to allow us to alter the properties of an incident sound wave in unprecedented ways. They are considered state-of-the-art when it comes to noise reduction and in the manipulation of wave properties in general.

After we ran the simulations we were able to identify what we believe to be the optimal combination of geometry and material composition for the attainment of the maximum amount of transmission loss. Going forward, as we intend to carry out this experiment in an acoustic chamber using 3D printed structures, we will be comparing the transmission loss graphs that we have attained from the simulation against the ones that we attain from conducting the proposed experiment.

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Nomenclature

$t_{i.ring}$= Height of the ith ring
m=mass of the ring
$r_{i.inner}$= Inner radius of the ring

TL= Transmission Loss
P_{inc}= Power of the incident wave
P_t= Power of the transmitted wave

CHAPTER 1: INTRODUCTION

1.1: BACKGROUND:

Noise reduction is a rather important yet unappreciated aspect of life in the modern ager. With all the hustle and bustle these days as a result of the countless machinations, locomotives and concentrated urban populaces around, taking steps to ensure one's own mental well-being and consistent performance in any work/task related endeavor. It has been demonstrated that a work-place that takes steps to ensure that there is a pleasant atmosphere for workers has led to an increase in the performance of the workers via an increase in worker comfort and morale [1].

For this reason, for our research we have decided to investigate the noise reduction capabilities of various solid structures in relation to their geometries and material compositions in order to determine the best combination of the two variables amongst a chosen pool of structures to ensure maximum noise reduction.

In particular we will be focusing on the use of acoustic metamaterials for our investigation. Acoustic metamaterials have proven themselves to be excellent at both noise reduction and to allow for the control of the properties of sound waves at low frequencies [2]. This fits our intended use for the structures well as we intend to mostly be working in the lower frequency ranges as that is where most of the background noise that distracts office workers reside in. As such the focus will be on minimizing those noise levels through the use of the aforementioned materials as much as possible.

One more thing that we wish to accomplish through this research is to highlight easily attainable materials and show that we can achieve a great degree of noise reduction even using those materials with the right geometric construction.

1.2: RESEARCH PROBLEM STATEMENT:

The problem that we aim to diminish through this research largely has to do with minimizing the amount of noise in office spaces as much as possible using materials that are easily attainable. We aim to do this through highlighting that even with these materials some variations in the geometry of the metamaterial will induce substantial differences in the overall noise reduction capability of the metamaterial.

1.3: OBJECTIVES:

- From our research choose some metamaterial structures that will be simple to construct.
- Choose a list of materials that will be easily attainable for the purposes of construction and experimentation
- Use COMSOL Multiphysics, namely the Acoustics Module of said software to simulate the noise reduction (through simulation of transmission loss) that each metamaterial will exhibit within the chosen frequency range
- Change certain parameters of the metamaterials, which for the purposes of our study will be restrained to the geometries and material compositions to find the best combination of the two that will yield the highest/most consistent transmission loss values.

1.4: SCOPE AND LIMITATIONS:

As stated before the scope of the study has to do with trying to find the optimum configuration of geometry and material composition to maximize the amount of transmission loss that a sound wave undergoes as a greater transmission loss will indicate that the metamaterial is better at noise reduction.

As previously indicated, first and foremost the use of the material that we will be constructing will primarily have to do with reducing the amount of noise that one would encounter in office spaces and conference rooms and the like. Due to that we will be dealing with a relatively low frequency range that will account for most sources of background noise.

From the literature that we have gone over we chose the metamaterial structures that have commonalities and are relatively easy to construct.

For our paper, the commonality that we have found in the structures used is that both of them utilize a membrane structure that will act as the primary means of reducing noise. As outlined in the objectives section, we will first keep the material composition of the membrane constant and change only the geometry of the structures used in order to determine which geometry induces the highest transmission loss. Afterwards we will be then taking those geometries and altering the material out of which the membrane is constructed. This will ensure that the absolute best construct based on the parameters that we are choosing to alter will be chosen for the purposes of further research and experimentation.

There are a number of factors though that may limit the accuracy of the transmission loss data obtained from running the simulations.

First and foremost to consider are the limitations that arise from the act of using a model itself [3]. By essence a model is a simplification of a real structure and thus cannot accurately portray all the changes the structure will induce into a sound wave as a result of its properties.

Furthermore we are limiting ourselves to the acoustics model of the structure that is used. This in and of itself can be thought of as a gross oversimplification as there are more phenomenon that are acting within the structure itself and how it affects the transmission loss of the waves. These will be discussed in detail further on.

1.5: THESIS OVERVIEW:

- First we went through a number of research papers as will be highlighted in the literature review section of the paper to determine the best structures that conform to the wanted conditions and parameters as per the purposes of this research.
- Once the papers were selected we recreated the structures in the paper using Solidworks 2016. As our intention was also to compare the transmission losses induced via geometrical changes we also changed some parameters of the structure dimensions and used them for our simulations.
- Afterwards we used the Acoustics Model of COMSOL Multiphysics to simulate the transmission losses that would be obtained from the structures should they be hit by a plane wave operating within the frequency range that we used for the study.
- We then chose a number of materials that also are in line with the conditions and parameters selected for the research.
- After selecting an appropriate geometrical configuration for the two structures we run further simulations using the different materials that are selected.
- The transmission loss graphs are then obtained and we use them to select the best material and geometry combination to be used to construct a sound absorbing wall or structure to be used in office spaces and the like.

1.6: THESIS ARRANGEMENT:

First we are going to be going over all the literature and relevant materials we went through to pinpoint the nature of our research and what elements and concepts we will be incorporating into our own work.

Second we will be going through the entire methodology of the research carried out. We will go through both the design process using SOLIDWORKS and the process of setting up and running the simulations using COMSOL.

Our next section will be comprised of presenting the results obtained from the simulations and us discussing the implications and conclusions that can be drawn from them.

The final component of the thesis will comprise of some concluding remarks regarding the nature of the work, where we intend to take it in the future and the importance of the research.

CHAPTER 2: LITERATURE REVIEW

2.1: INTRODUCTION:

The geometric structures that we used for this paper was taken from two research papers in particular. They were ones that dealt with the transmission losses of membrane type metamaterial with coaxial ring masses [4] and one that used a hexagonal structure that was to be arranged in a honeycomb pattern [5]. We chose these two structures for our simulations because we believe them to be the most viable in terms of being easy to manufacture and produce for the purposes of experimentation and commercial use.

2.2 IMPORTANT TERMS:

Acoustic Metamaterials: They are materials that are built in ways that allow us to manipulate sound waves in ways that would not be possible using conventional materials. The best example is that metamaterials can be used to construct geometries that allow for zero or even negative refractive index of sound [6].

In short acoustic metamaterials are physical objects constructed for the purposes of allowing for extremely precise manipulation of sound waves [7].

Figure 2.1: An example of a constructed acoustic metamaterial [7]

Transmission loss: What we are using to measure noise reduction. Simply put, transmission loss can be thought of as the degree to which sound levels are reduced as they pass through an acoustic barrier [8].

Another way to define the transmission loss is to view it as the ratio of the sound energy transmitted through a barrier/treatment compared to the sound energy that was transmitted as an incident wave [9].

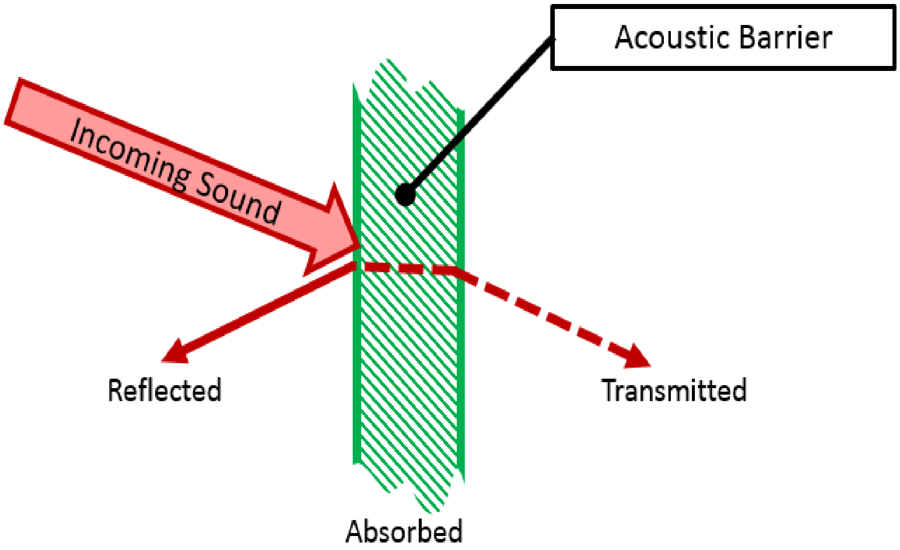


Figure 2.2: A simplified view of how transmission loss works [9]

2.3 GEOMETRIES USED:

As mentioned before we primarily used two geometries that we believed would best serve the purposes of our research, being the ring mass and hexagonal structures, the two structures that we have created as a baseline are:

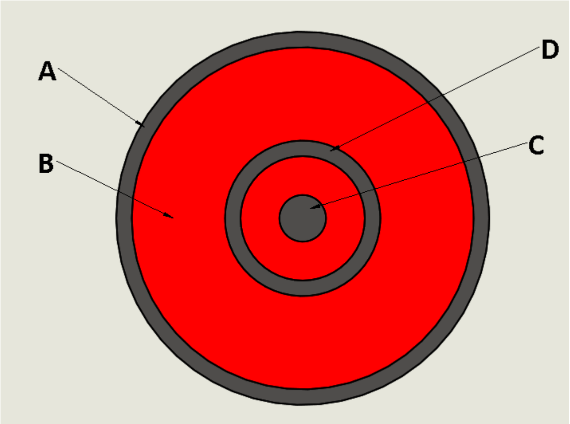


Figure 2.3: The coaxial ring mass model [4]

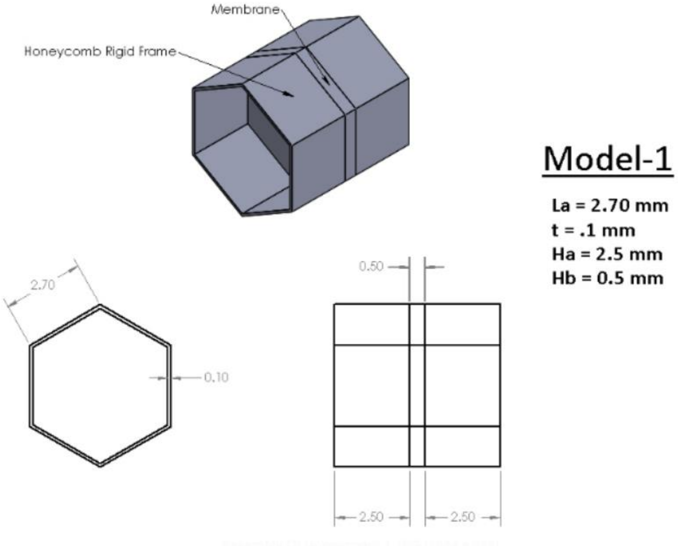


Figure 2.4: The hexagonal cell model [5]

The reasons for which the structures above were chosen are twofold. The primary reason was because of the common element shared by the two structures. They both test the transmission loss created by an acoustic metamaterial that makes use of a membrane structure. As such we will be using those structures as they would facilitate our intention to use them for research.

2.4 OUR WORK:

The papers that we are using above both deal with the transmission losses incurred through the materials that are used however we make some changes to the methodology ourselves to better suit our own purposes. The first change that we make is that the simulations that we run alter the material composition of the membranes that are used in the paper. This is something that neither of the papers that investigate the transmission loss effects of the structures do. The other change is one concerning the paper dealing with the hexagonal structures. That paper only investigated the transmission loss using one geometrical configuration and using only one material for the structure. In our research we altered both those parameters.

CHAPTER 3: METHODOLOGY

3.1: INTRODUCTION:

Here we will go through the exact process of designing and then running the simulation of the metamaterial in detail. To serve as a brief overview, what we did first was select the structures, then use SOLIDWORKS 2016 to design the structures in question and then use the Acoustics Module of COMSOL Multiphysics to run the simulations and find the expected transmission losses. We will be going through the steps outlined above in detail.

3.2: SELECTION AND DESIGN:

The process that was used to select for the best two metamaterial structures to use in our simulations were dependent on selecting for a number of factors. As we know metamaterials do allow for us to manipulate the properties of a sound wave in ways that would not be possible using conventional waves. What we wanted to select for are metamaterials that will be easy to construct, demonstrate good acoustic performance in low frequency conditions and have elements of commonality that allow for us to more easily compare the performance of the two structures. Ultimately we decided on two: The Hexagonal Cell and the Ring Mass Structures.

3.2.1 Ring Mass Structures:

The basic structure for ring mass structures consists of a membrane (polyetherimide) stretched in tension, a support structure, and a centrally located mass. The mass is surrounded by 3 rings constructed of 18/8 steel. This material is also used for the construction of both the central mass and the outer support structure.

The first step of our research was to take the structure given in the paper that we have used as a reference and recreate it using Solidworks 2016. The parameters that we have used to create the ring masses are given below:

Configuration	Central Mass (g)	Ring 1 mass (g)	Ring 2 mass (g)	Ring 3 mass (g)	Ring 1 radius: inner, outer (mm)	Ring 2 radius: inner, outer (mm)	Ring 3 radius: inner, outer (mm)
Model 1	0.16	0.16	-	-	4, 5	-	-
Model 2	0.16	0.16	0.16	-	4, 5	7, 8	-
Model 3	0.16	0.16	0.16	0.16	4, 5	7, 8	10, 11

Table 1: The dimensions of the constructed ring mass structure [4]

Table 1 shows us the parameters (namely the radius of the ring masses) that are important for the construction of the material.

Taking these values from the reference paper we created 3 different structures to be used for our simulation. These structures were:

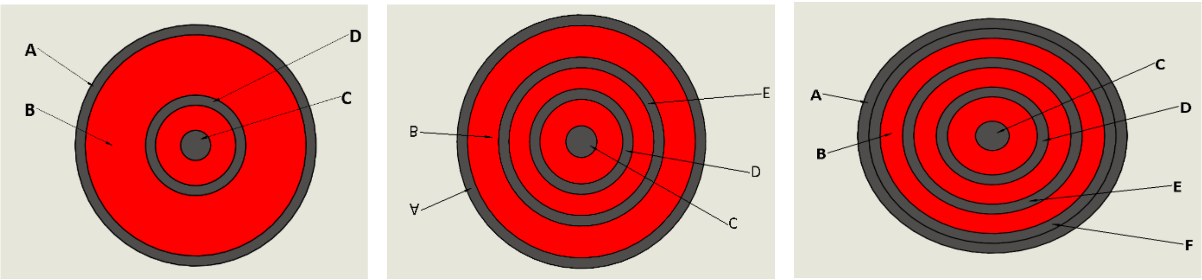


Figure 3.1: The three ring mass structures used for our simulation.

Here,
A= the support ring
B= the membrane (highlighted in red as that is the component who's material composition we are changing)
C= the central mass
D,E,F= the ring masses used

In accordance with the reference paper we use a special formula to determine the height of the ring masses used. These heights are determined using the formula:

Equation 1: $t_{i,ring} = \frac{m}{\pi\, \rho\, r_{i,inner}^2}$ [4]

Here, t_i refers to the height of the ring in question, m refers to the mass of the ring and ρ is the density. The ring was assumed to be comprised of 18/8 stainless steel as per the reference paper, and we assumed that the support structure and central mass were constructed from the same material.

The required material properties and their values were found [10] and those values were input in the simulation software.

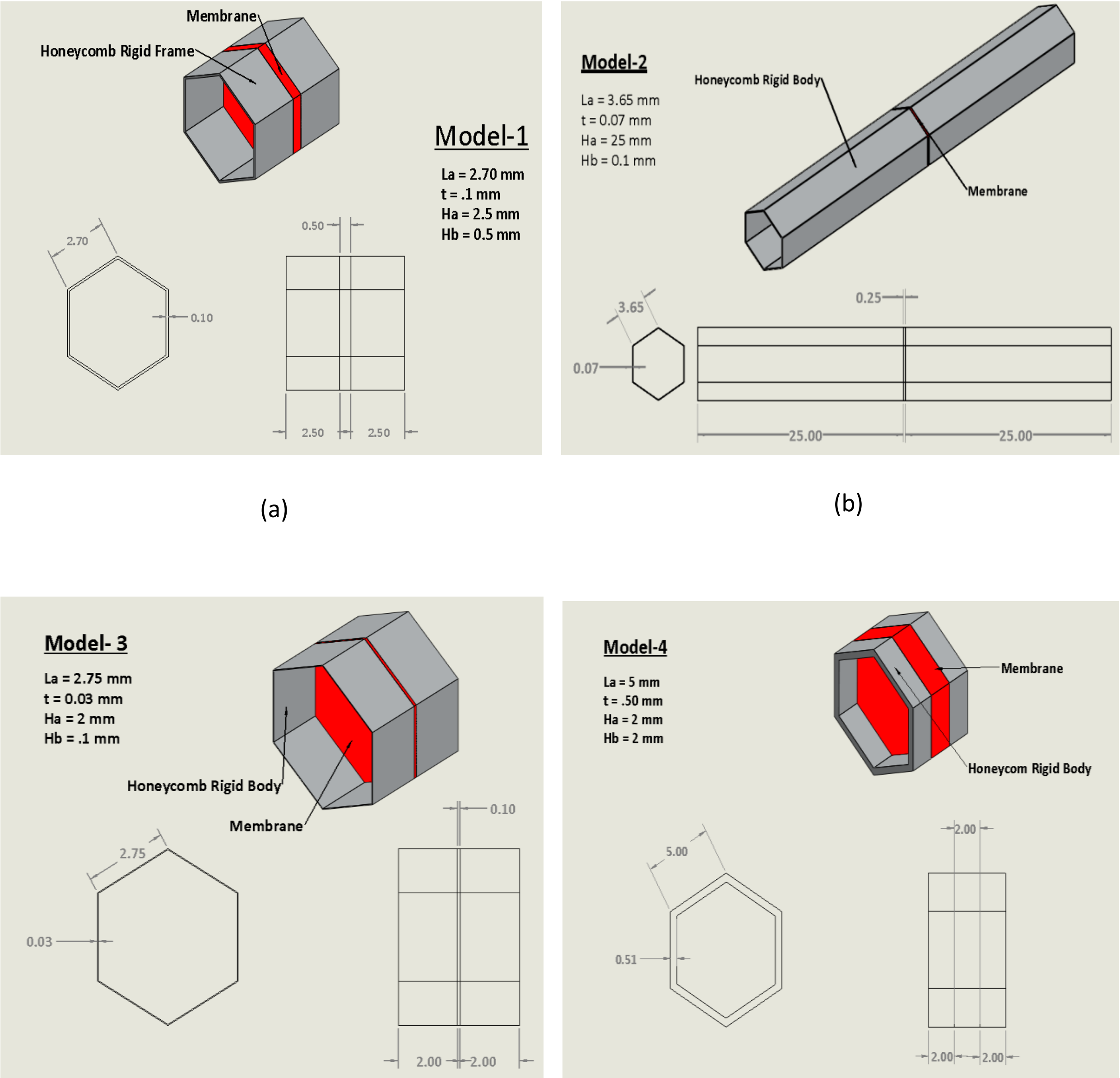
3.2.2 Hexagonal Cell:

Like the previous structure that we used the hexagonal cell was also constructed using the paper as a reference. However during the design process we did make a number of modifications to the original design to better suit the purposes of our research. Similar to what we did with the ring mass structures we used the reference paper dimensions as a base. The dimensions used for the original hexagonal structure (that we denote as hexagon model 1) are given below in table 2:

Dimension Parameters (mm)	Model 1	Model 2	Model 3	Model 4
Side length (La)	2.7	3.65	2.75	5
Boundary wall thickness (t)	.1	.07	.03	.5
Height of Hexagonal (Ha)	2.5	25	2	2
Height of Membrane (Hb)	0.5	.25	.1	2

Table 2: Dimensions of the constructed Hexagonal Cell structure [5]

Based on the dimensions above 4 different geometric models for hexagonal cells were created. The models were as follows:



(a)

(b)

(c)

(d)

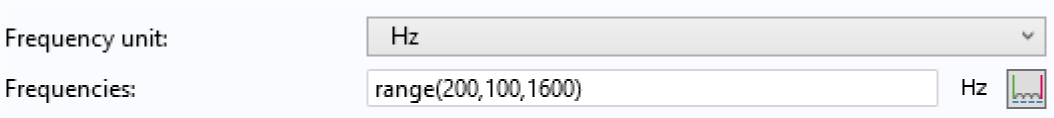
Figure 3.2: The 4 constructed Hexagonal Cell models

3.3 SIMULATION:

For our experiment the best way to run our simulations was to use the Acoustics Module of COMSOL Multiphysics. It is a tool that allows us to adequately model and simulate the noise reduction performance of the structures [11].

The first step of the simulation was to set up the necessary starting parameters and the equations that will represent the incoming and outgoing power of the incident and the outgoing sound waves respectively. After that we will go on to also set up the different equations for modelling the transmission loss.

Once that is set-up, we frequency range for which we want the simulation to run and then graph the transmission loss against the frequency. The frequency range that we used is form 200Hz to 1600Hz.



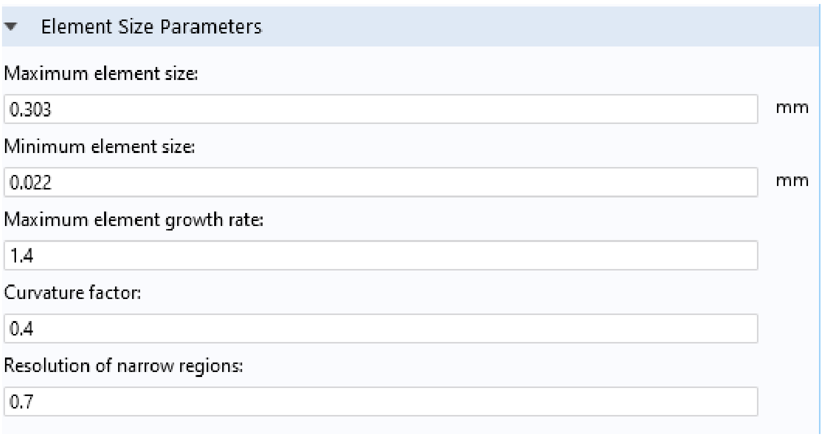
Frequency unit: Hz

Frequencies: range(200,100,1600) Hz

Figure 3.3: The frequency range that we use for the simulation in COMSOL.

The value in the middle (100) is the step value and it denotes the intervals at which a result of the frequency can be attained (200, 300, 400, etc.)

We also kept the mesh sizes for each of the geometries used constant as part of the simulations. The mesh sizes that are used for the simulation are:



Element Size Parameters

Maximum element size: 0.303 mm

Minimum element size: 0.022 mm

Maximum element growth rate: 1.4

Curvature factor: 0.4

Resolution of narrow regions: 0.7

Figure 3.4: Mesh element sizes that are used for the simulations.

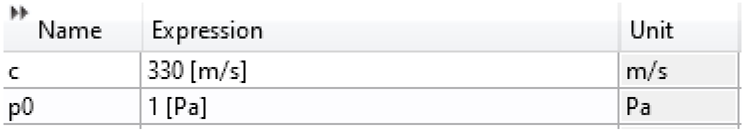
The average time taken for each of the simulations are as follows:

Hexagonal Cell: 45 seconds
Ring Mass Structures: 5 seconds (lower computational load due to use of 2D axisymmetric structure)

As with the previous section we will breakdown the simulation process in detail for both the ring mass structure and then the hexagonal cell structure.

3.3.1 Ring Mass Structure:

First what we did was layout the necessary starting parameters of the air that we 2ill be modelling. Mainly the speed of sound [12] and the atmospheric pressure [13]. Alongside that we use the paper as a reference to determine what the initial pressure condition (denoted as p0 in the simulation) will be. We set those as our global parameters.



Name	Expression	Unit
c	330 [m/s]	m/s
p0	1 [Pa]	Pa

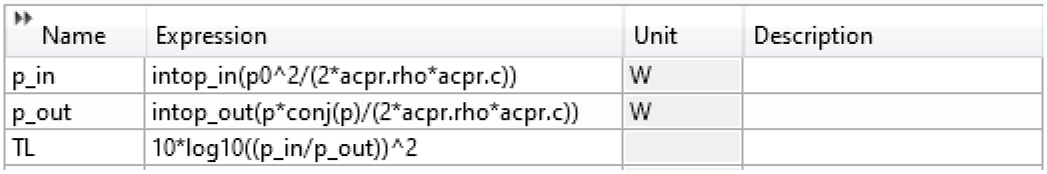
Figure 3.5: The table of initial universal parameters that we input into the COMSOL Acoustics Module

After we set those values are next order of business was to input the necessary equations that would denote the incoming and the outgoing power as the transmission loss of the sound waves as it passes through the structure. The equation for the transmission loss was taken from the reference paper that was used and was set as:

Equation 2: $TL = 10\log(\frac{p_{inc}}{p_t})^2$

Here, P_{inc} refers to the power of the incident wave and P_t refers it the power of the transmitted wave [14].

The equations were then also put into the simulation.



Name	Expression	Unit	Description
p_in	intop_in(p0^2/(2*acpr.rho*acpr.c))	W	
p_out	intop_out(p*conj(p)/(2*acpr.rho*acpr.c))	W	
TL	10*log10((p_in/p_out))^2		

Figure 3.6: The variables involved and the expressions used taken from COMSOL

The next step of setting up the simulation was to specify the material properties of what was going to be used. For the purposes of our research we used 4 different materials for the different simulations we would run and compare. The materials we use for this analysis are given in the table below:

Material	Density (kg/m3)	Young's Modulus (Pa)	Poisson's Ratio
Silicon Nitride	3100	$250*10^9$	0.23
EVA	1800	$8.6*10^8$	0.45
Polyethylene (PE)	952 - 965	$1.07*10^9$ - $1.09*10^9$	0.029–0.038
Polyetherimide	1200	$3.6*10^9$	0.36

Table 3: The Materials used for the simulations and their properties

While there are four materials given here, for the first step of the simulations we will be keeping the material constant and only alter the geometries to find the transmission loss differences induced by them. Since we are currently working with the ring mass structures, we will be using the differences in the number of rings to create different geometries to simulate. For both structures we are going to be using Polyetherimide as the constant first just to do the geometrical comparison.

One crucial step of setting up the material simulations was to find out the speed of sound that is applicable for each of the materials. For this purpose, we use the speed of sound equation in a solid which is dependent on the Young's modulus and the density [15], both of which can be found from the table provided.

Equation 3: $\nu = \sqrt{\frac{Y}{\rho}}$

Here, v= Velocity of sound wave
Y= Young's modulus
p= Material Density

For the first step we decided to use polyetherimide as a constant material and change the geometries of the structure by changing the number of rings.

The incident wave was modelled as a planar wave with an initial pressure of 1Pa as per the reference paper. We used only the acoustics module of the simulation software.

One other change we also make during the simulation process of the ring mass structure is that instead of using the 3D Model that we constructed, we use a 2D axisymmetric design for the structure.

A 2D axisymmetric figure was used to facilitate the use of the simulation software. It made the process simpler as there are fewer elements to process and the accuracy is not sacrificed.

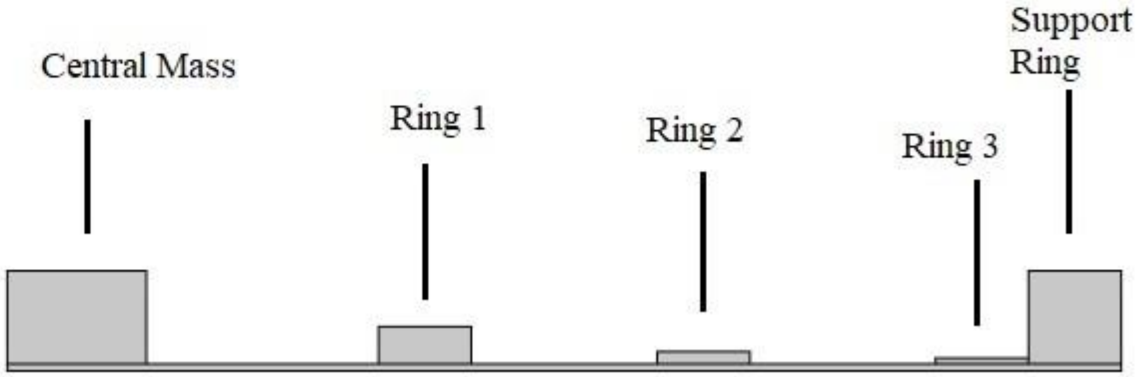


Figure 3.7: The 2D axisymmetrical model to be used for the simulation

As a result, we obtained a number of graphs. In the graphs the frequency is on the x-axis and is from the range of 200 Hz to 1600Hz. The transmission loss obtained from the calculations are on the y-axis.

3.3.2 Hexagonal Cell:

For hexagonal cell structures the initial setup of the simulation with the relevant variables and parameters will be identical to what is laid out with the ring mass structures. Just as before first we will be obtaining some graphs whilst keeping the material constant and changing only the geometry. To begin we will be choosing one material (polyetherimide) and changing only the geometry to see which geometrical structure gives us the best transmission loss values.

For this simulation we use a different transmission loss equation. The one we use is as follows:

Equation 4: $TL = 10\log(\frac{p_{inc}}{p_t})$

Unlike the previous simulations though we will be using 3-dimensional structures to simulate the hexagonal cells:

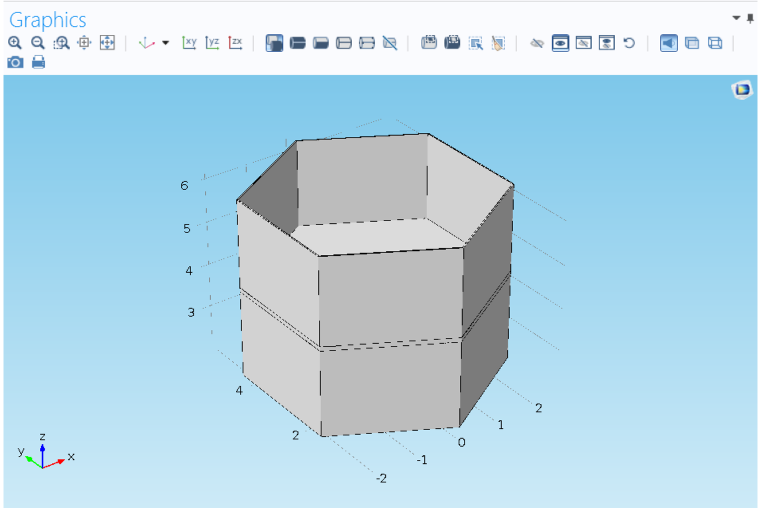


Figure 3.8: The hexagonal shape that we constructed and then put into the simulation software

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Ring Mass Structures:

From the simulation setup outlined in the previous section we obtain these 3 graphs:

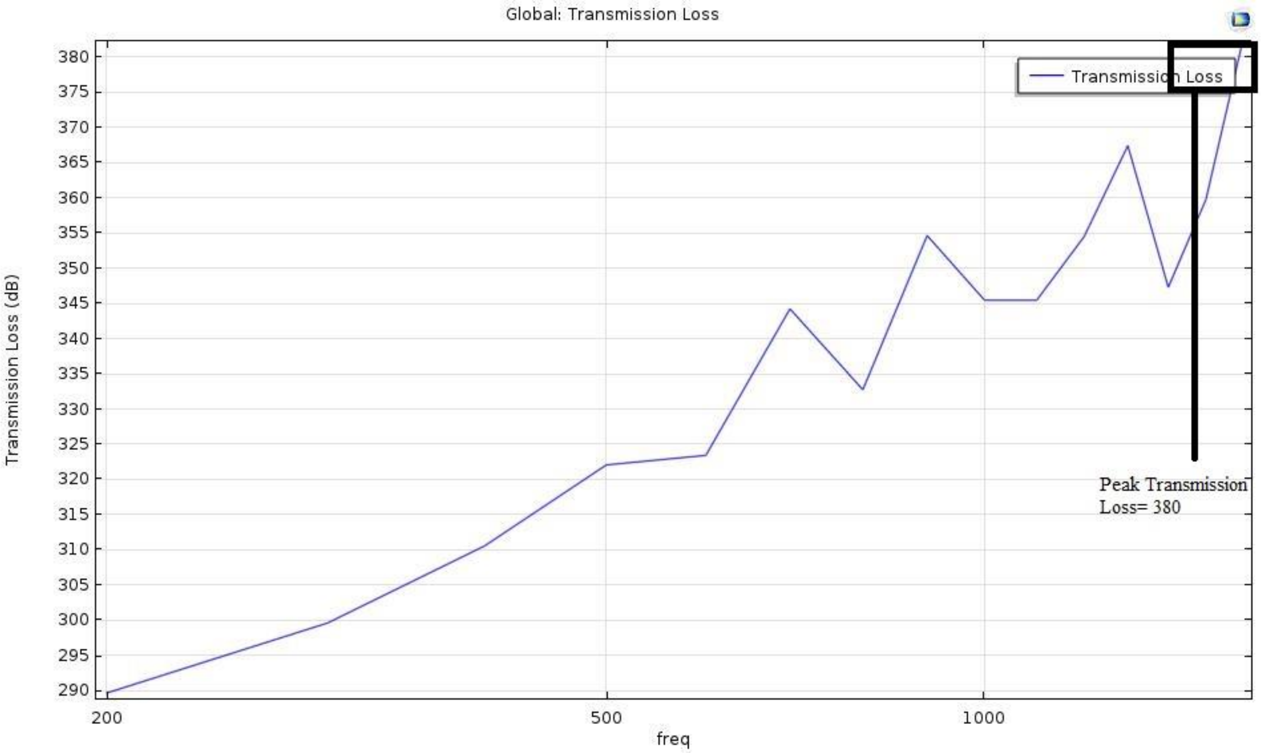


Figure 4.1: Transmission loss graph of 1 ring coaxial ring mass structure using polyetherimide membrane

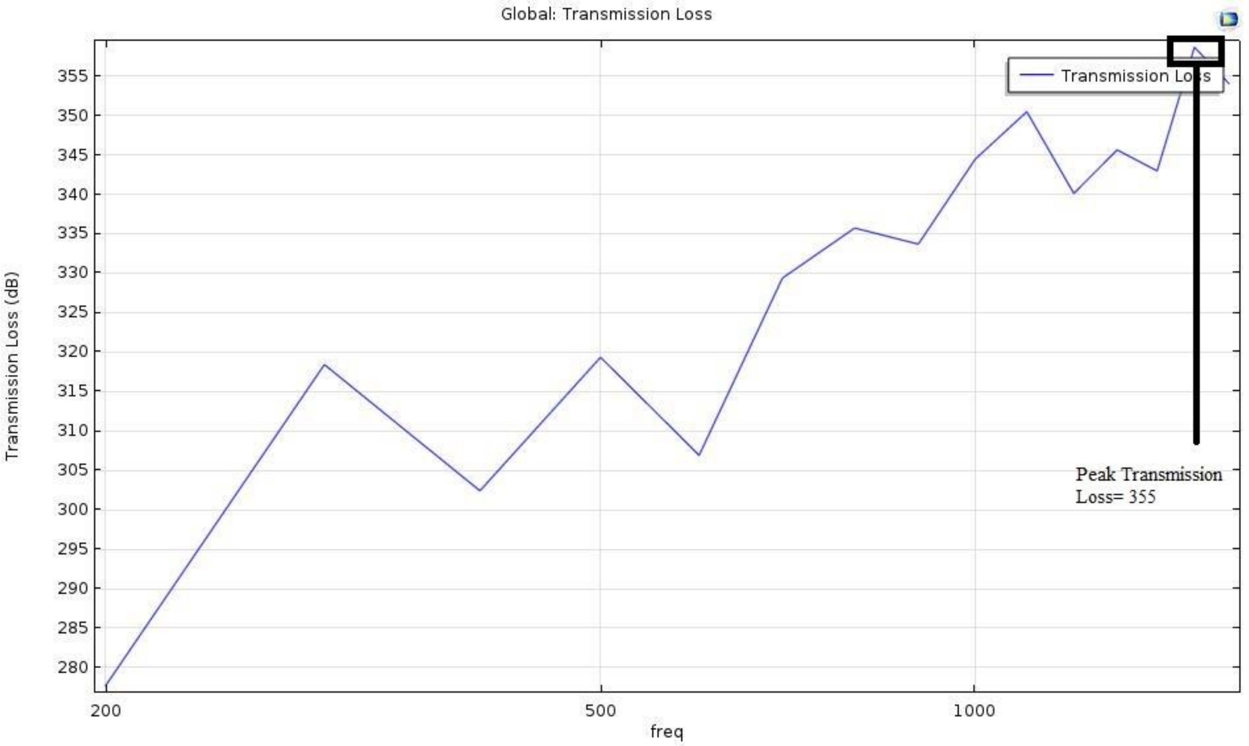


Figure 4.2: Transmission loss graph of 2 ring coaxial ring mass structure using polyetherimide membrane

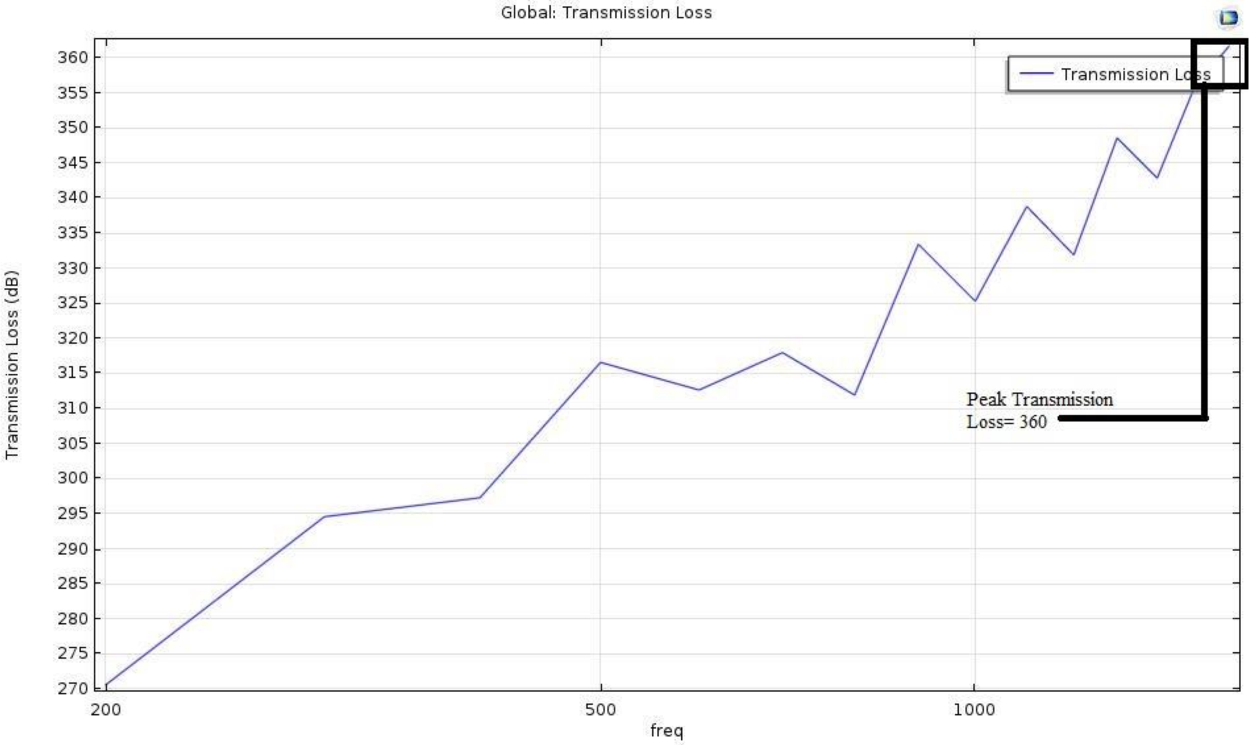


Figure 4.3: Transmission loss graph of 3 ring coaxial ring mass structure using polyetherimide membrane

Ring Mass Structure Graph (Geometry)	**Peak Transmission Loss**
1 ring	380
2 rings	355
3 rings	360

Table 4: The Maximum Transmission Loss of the Coaxial Ring Mass Models based on geometry

Afterwards we analyze these 3 graphs and we determine the best of the three geometric models that we have at our disposal is the one that gives us the greatest amount of transmission loss.

Overall it was determined that the model with 2 rings gives us the best values of transmission loss in terms of both consistency and maximum value. So that is the model that we will be using for the changes of material.

The 2 ring structure was chosen despite the 1 ring and 3 ring structures seemingly having higher transmission losses on the surface because despite the lower peak transmission loss calues if we actually look at the graph we can see that the 2 ring model gives us the most consistent performance across the entire range of frequencies.

Once that is chosen we simulate the chosen structure using different materials. The 4 materials that are chosen for the simulation are: the aforementioned polyetherimide, polyethylene, silicon nitride and EVA. These materials were chosen for their ease of access and the ease with which future experiments can be carried out with them.

From further simulations using the above materials we attain these four graphs:

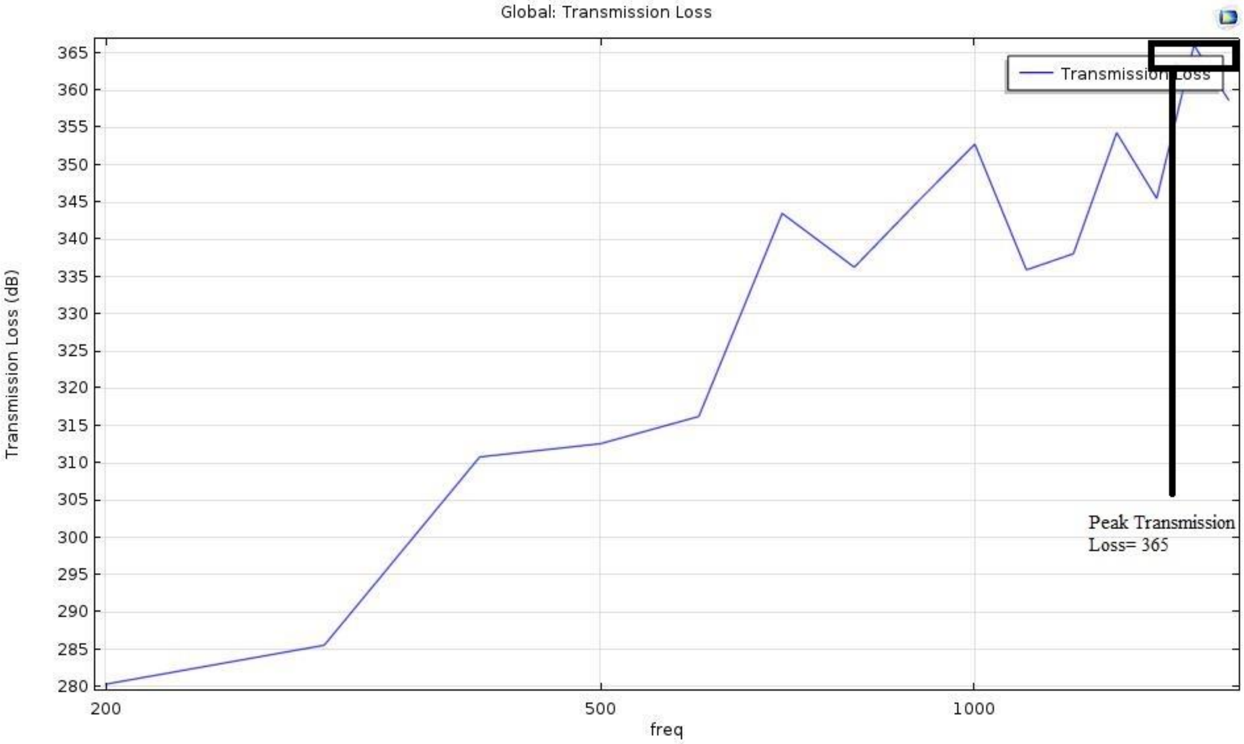


Figure 4.4: 2 ring configuration using EVA (Ethylene-Vinyl Acetate) as membrane material

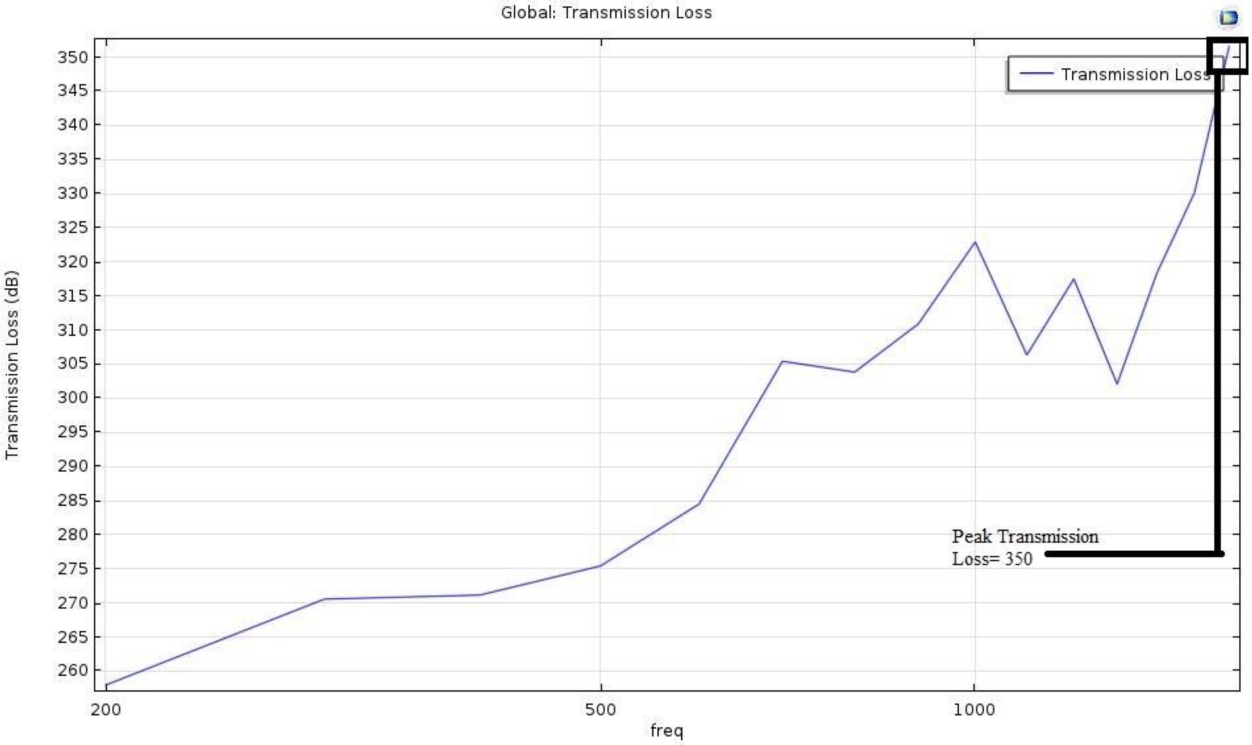


Figure 4.5: 2 ring configuration using Silicon Nitride as membrane material

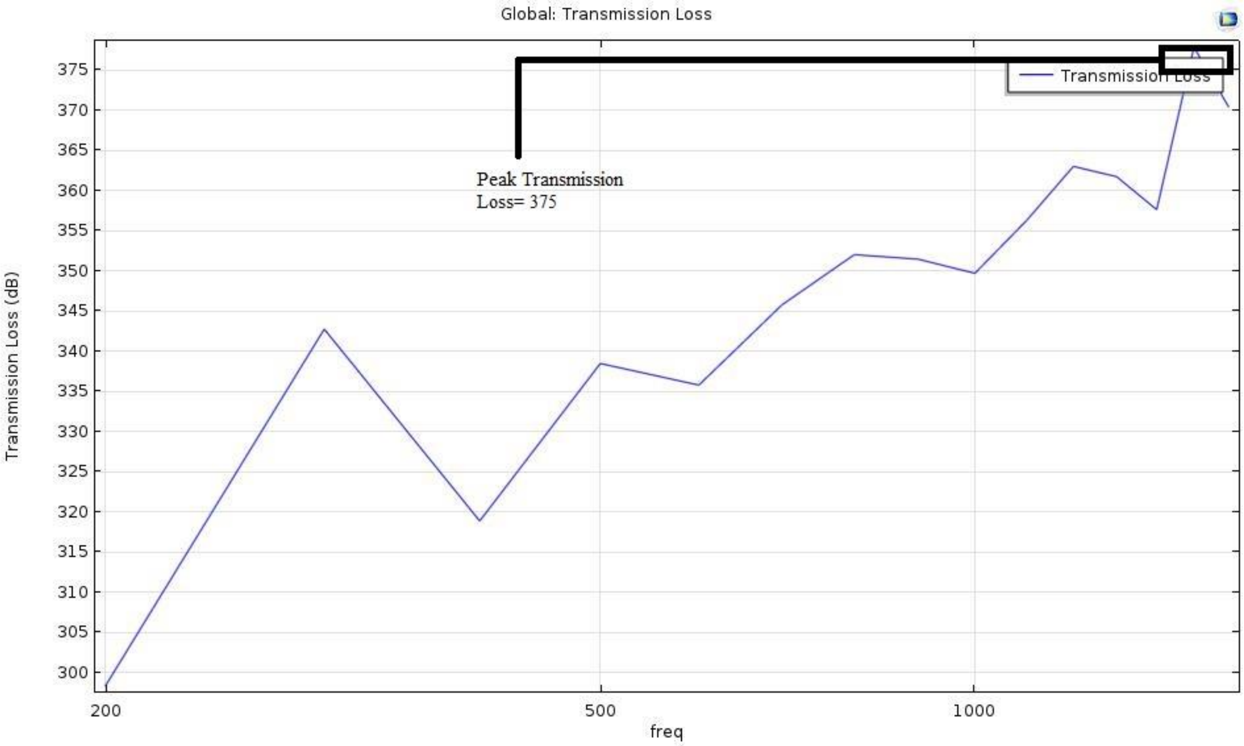


Figure 4.6: 2 ring configuration using Polyethylene as membrane material

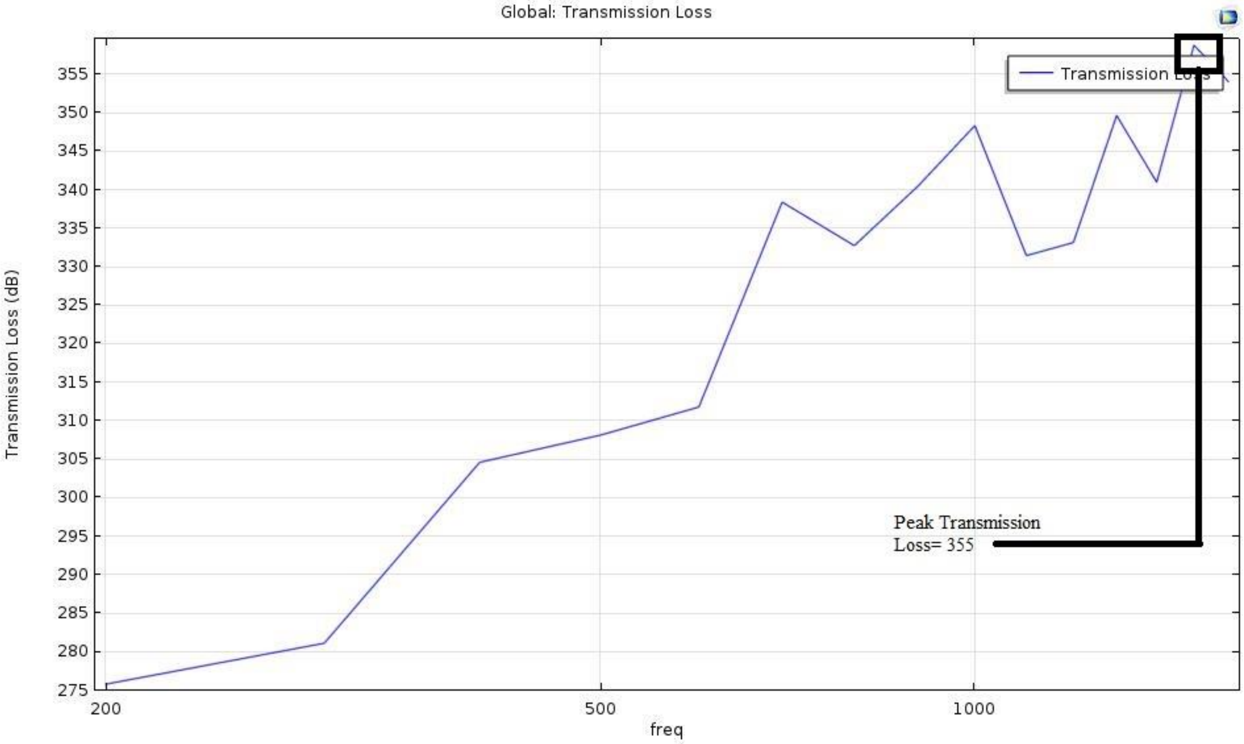


Figure 4.7: 2 ring configuration using Polyetherimide as membrane material

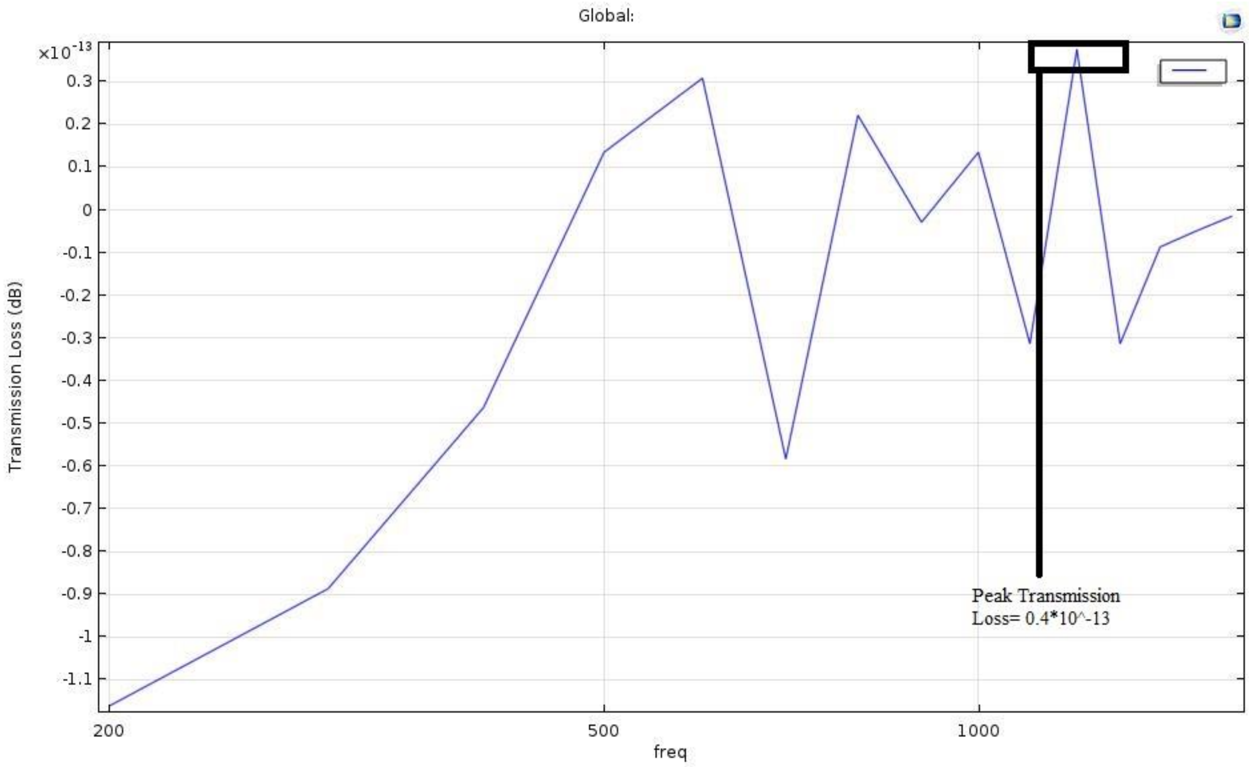
Ring Mass Structure Graph (Material)	**Peak Transmission Loss**
EVA	365
Silicon Nitride	350
Polyethylene	375
Polyetherimide	355

Table 5: Peak transmission loss exhibited by 2 ring structures of different material compositions

From the graphs as well as the table above we can see that polyethylene gives us the best values in terms of the maximum transmission loss that is obtained (at 375) and in terms of consistently high transmission loss values. Therefore polyethylene is the material that we will choose for further experimentation.

4.2 Hexagonal Cell Structure:

The graphs obtained are as follows:



Peak Transmission Loss= 0.4*10^-13

㊱ Figure 4.8: Transmission Loss graph of Hexagonal Cell Model 1 using polyetherimide

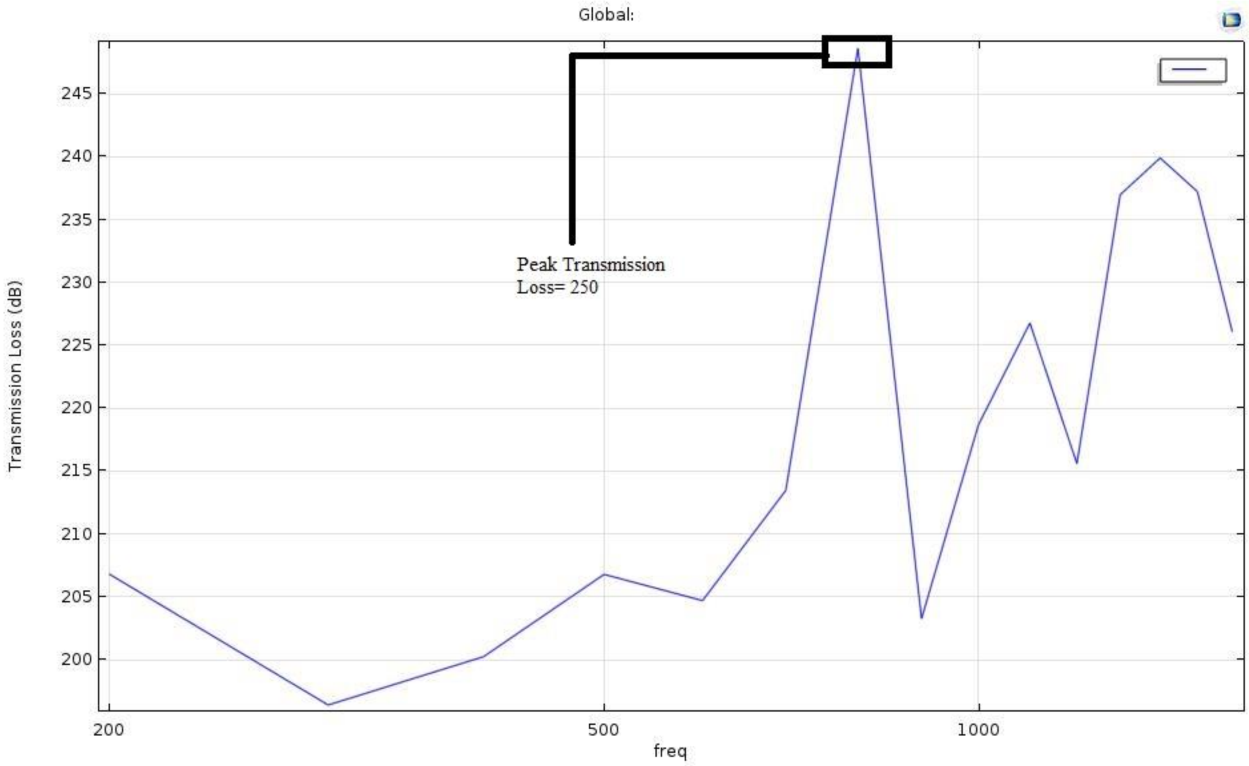
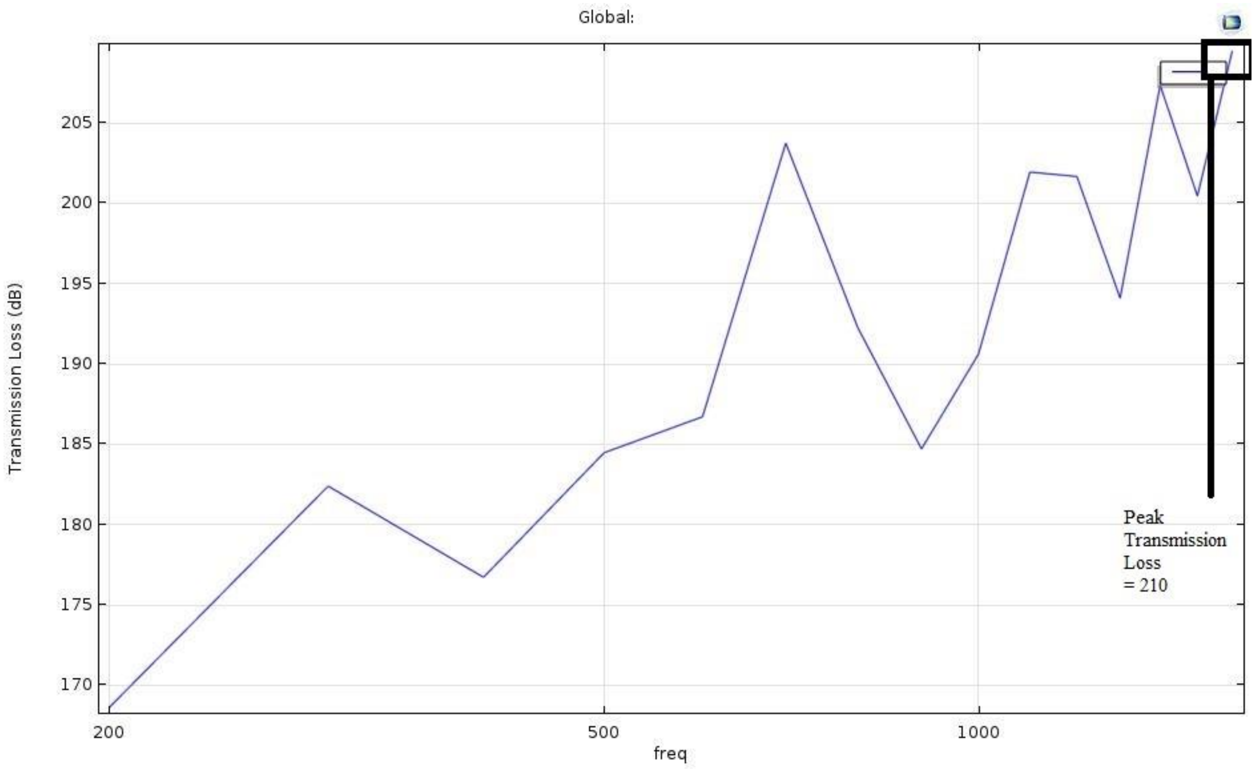
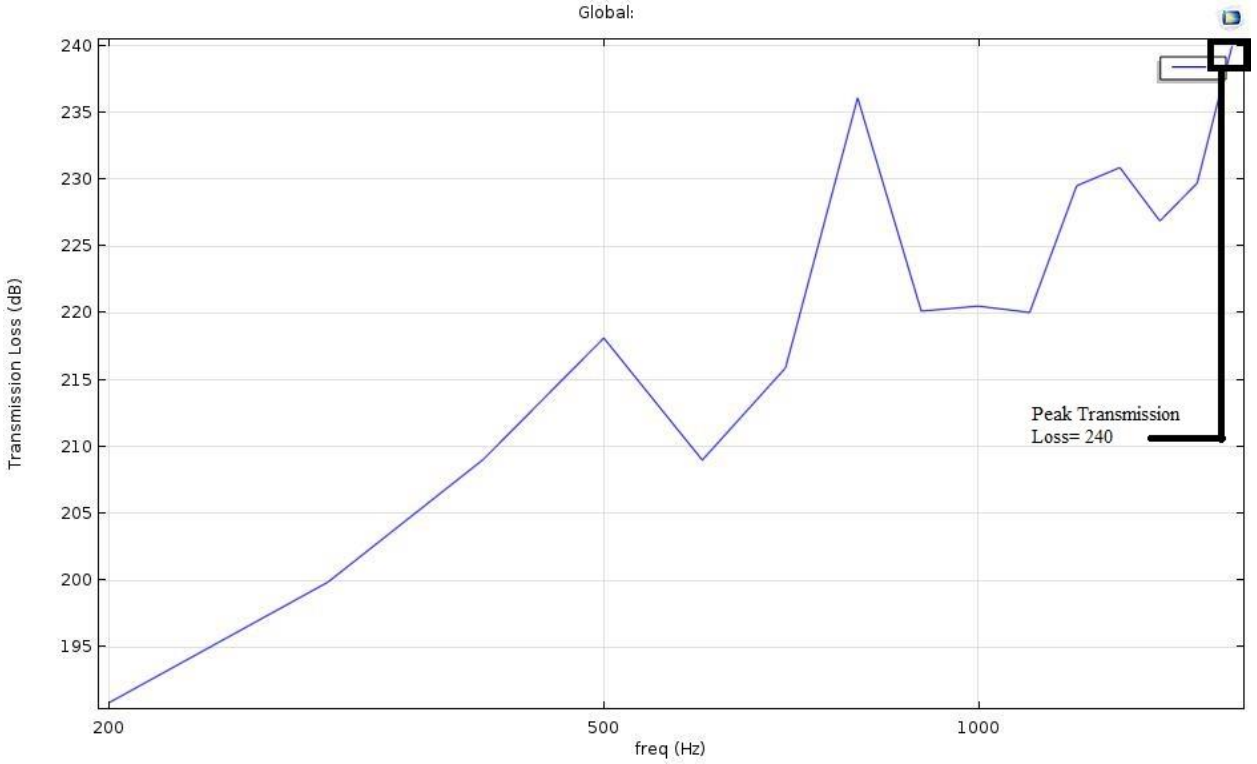


Figure 4.9: Transmission Loss graph of Hexagonal Cell Model 2 using polyetherimide



Peak Transmission Loss = 210

Figure 4.10: Transmission Loss graph of Hexagonal Cell Model 3 using polyetherimide



Peak Transmission Loss= 240

Figure 4.11: Transmission Loss graph of Hexagonal Cell Model 4 using polyetherimide

Hexagonal Cell Graph (Geometry)	**Maximum Transmission Loss**
Model 1	$0.4*10^{-13}$
Model 2	250
Model 3	210
Model 4	240

Table 6: The Maximum Transmission Loss of the Hexagonal Cell Models based on geometry

From the graphs above we can immediately discount the results obtained from model 1 as they appear to be anomalous in nature and not at all congruent with the other models and their results. We can discount model 3 as the maximum attained transmission loss for the model remains markedly less than what is obtained for the others. Between models 2 and 4 we use model 4 because if we were to observe the graph for model 2 we would find that the transmission loss is very low for the lower frequency range (namely the 0-500 Hz range) whereas performance in terms of transmission loss for model 4 appears to be much more consistent throughout. So we choose model 4 for the purposes of experimentation.

Afterwards, much like with the ring masses we use model 4 as a base and change the material composition of the membrane and simulate the transmission losses from there. Doing so gives us four more graphs:

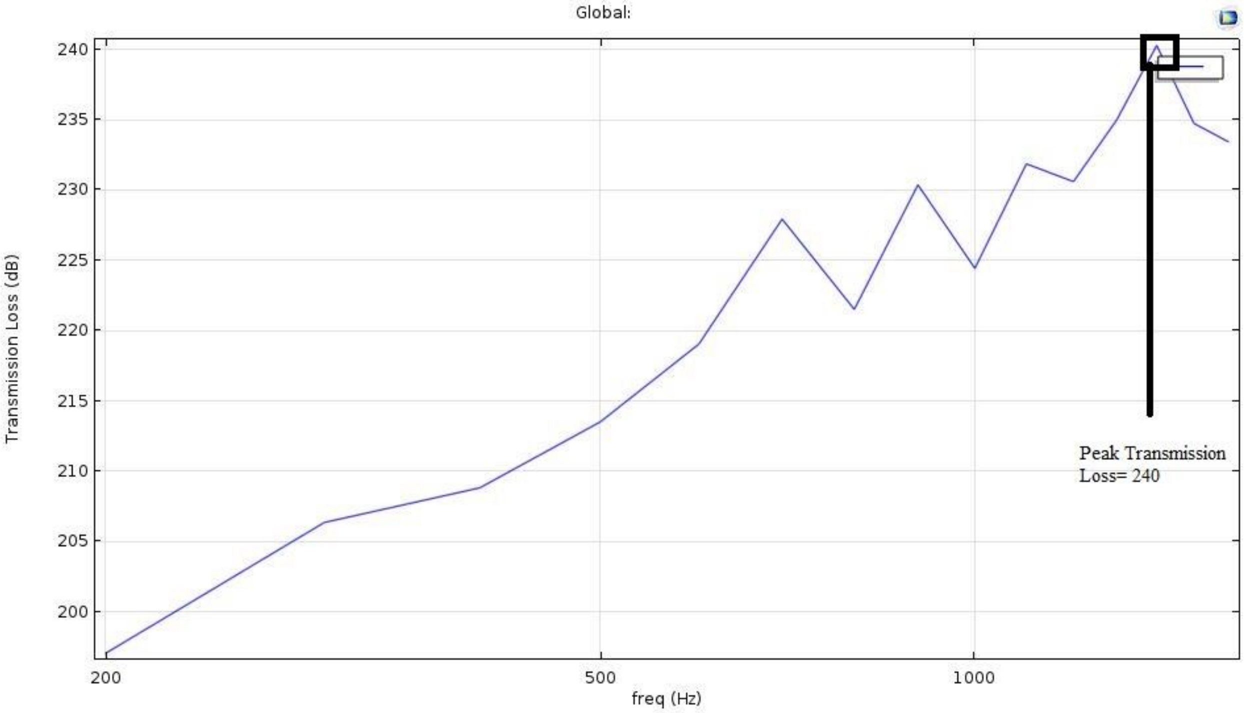


Figure 4.12: Hexagonal Cell Model 4 with Polyethylene membrane

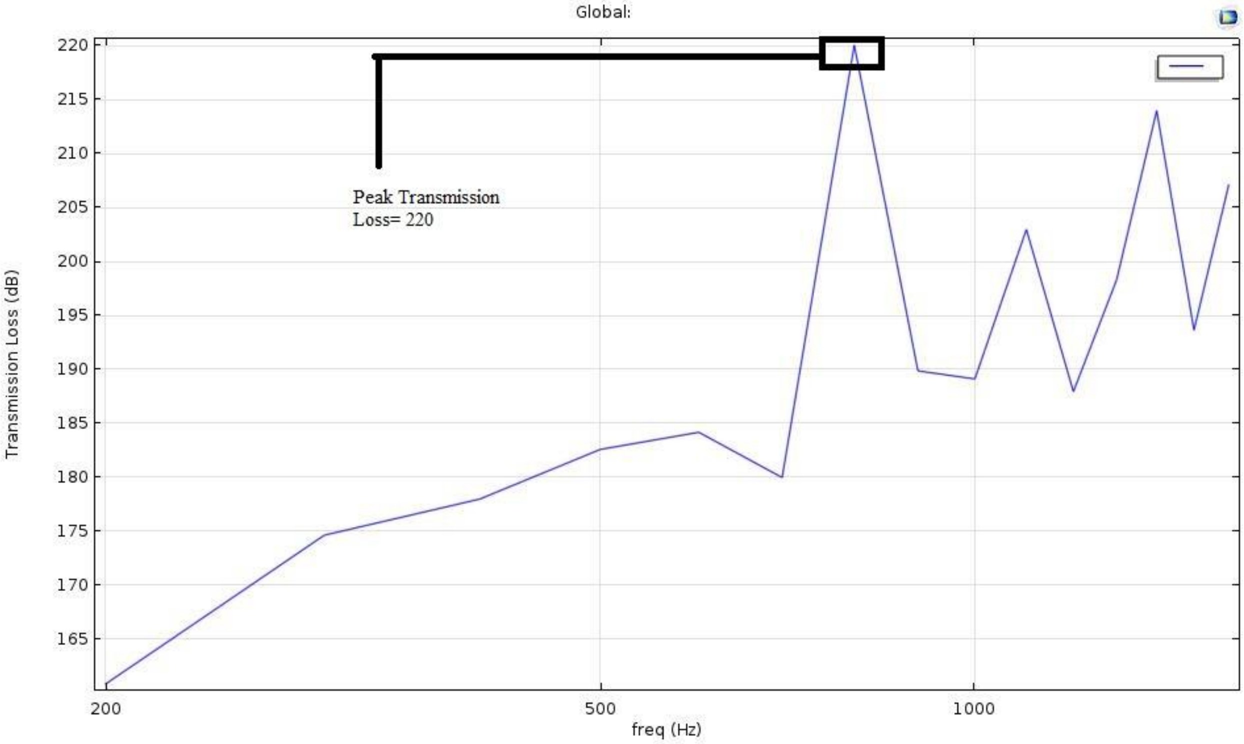


Figure 4.13: Hexagonal Cell Model 4 with Silicon Nitride membrane

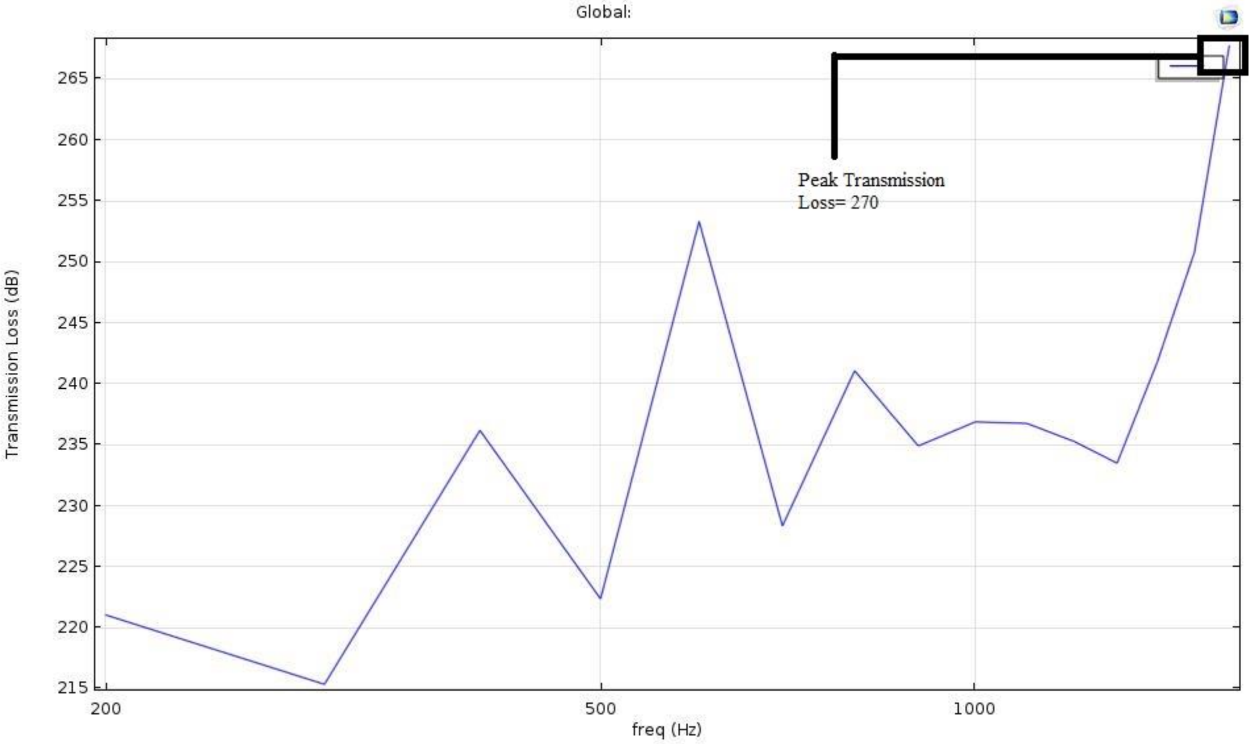


Figure 4.14: Hexagonal Cell Model 4 with EVA (Ethylene Vinyl-Acetate) Membrane

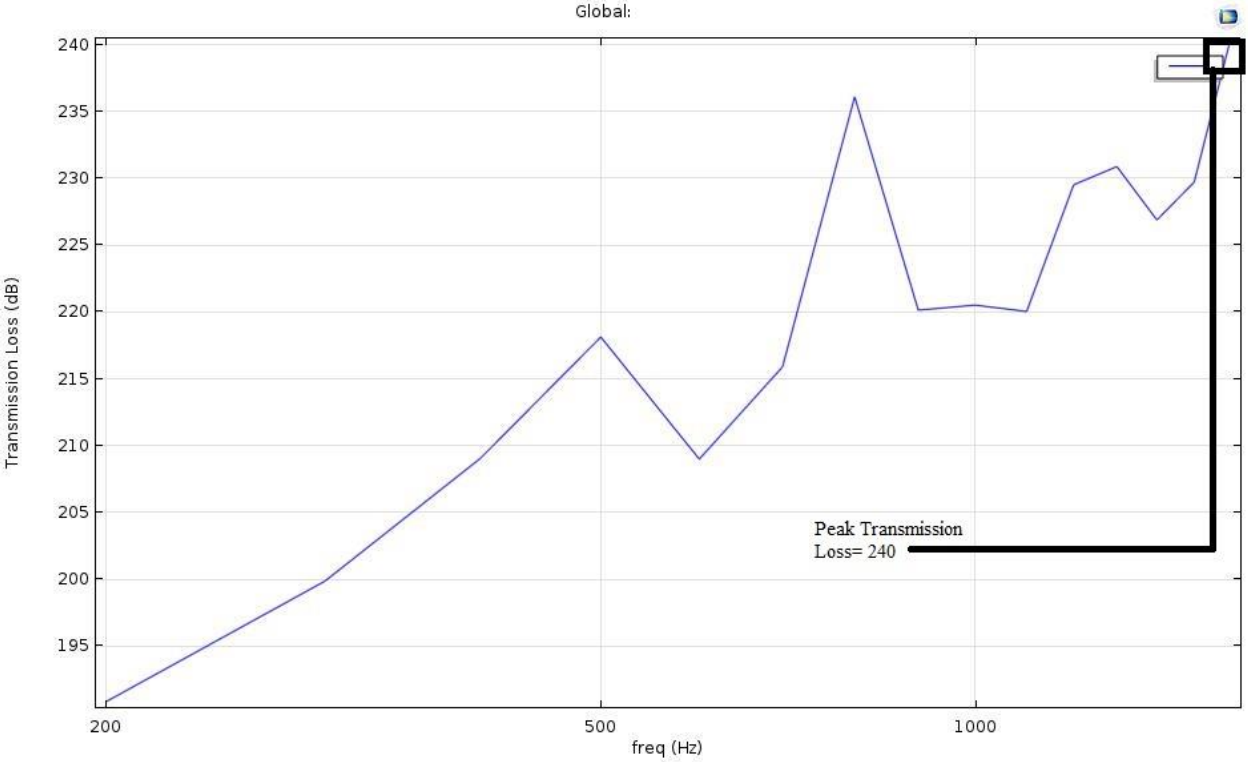


Figure 4.15: Hexagonal Cell Model 4 with Polyetherimide Membrane

Hexagonal Cell Graph (Material)	Peak Transmission Loss
EVA	270
Silicon Nitride	220
Polyethylene	240
Polyetherimide	240

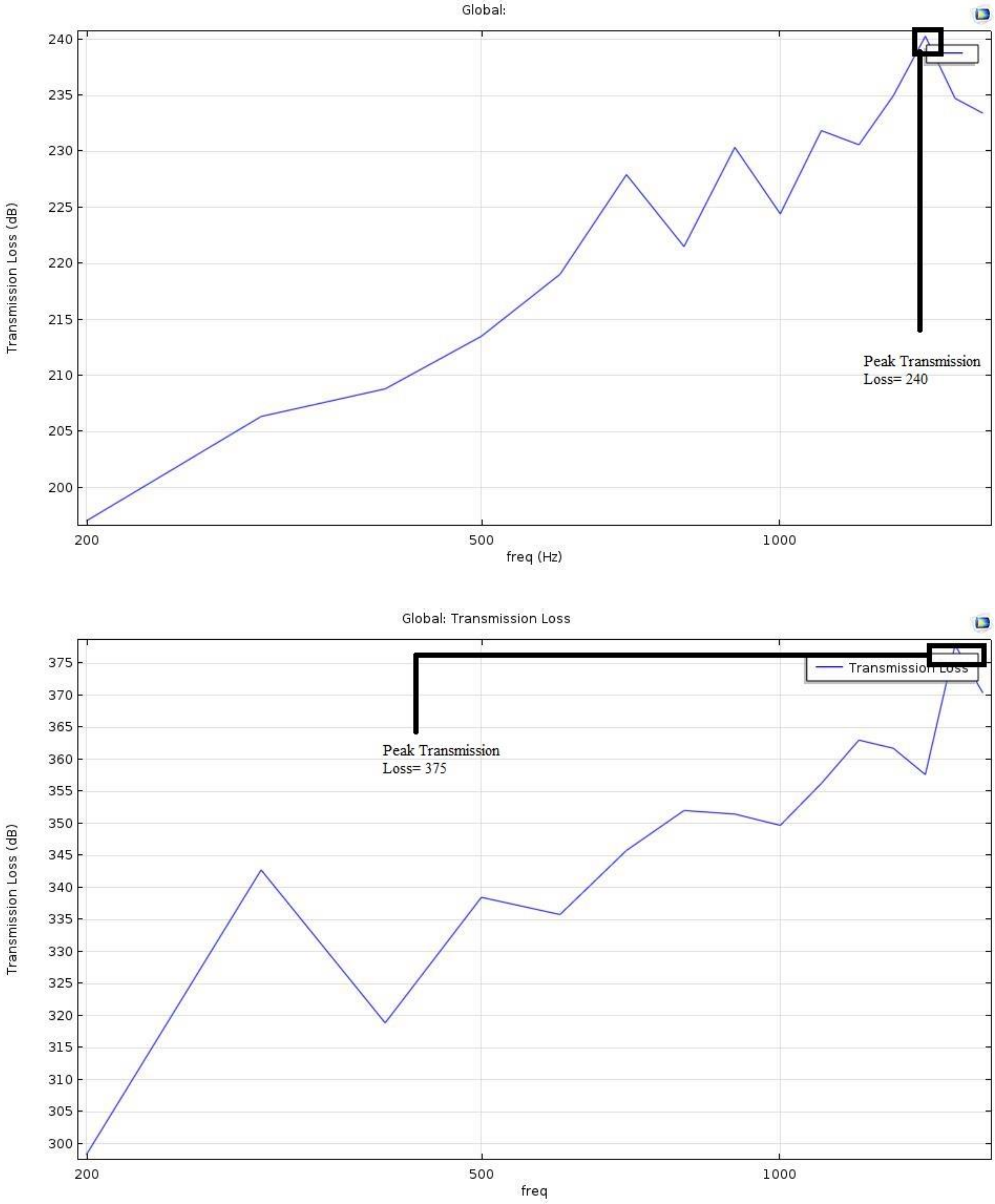
Table 7: Peak Transmission Loss of Hexagonal Cell Model 4 with different membrane materials

From the table above we can see that it is EVA that gives us the maximum transmission loss. However its performance at lower frequency ranges show extensive instability and has many peaks and troughs throughout its range. As such it is not the optimal material to use for our intended use.

It is from the four graphs that we obtain above that we try to determine the one that gives us the best values for transmission loss. The one we choose is the model that uses polyethylene as the membrane material. Interestingly this is the same material that was chosen to be the best of the material options even during the simulations of the ring mass structures.

4.3 Direct Comparison:

Since we have gone on to select the 2 rings model for coaxial ring masses and model 4 for hexagonal cell structures the next phase of the experiment is to directly compare the two models in order to find out which one gives us the best transmission loss overall.



Peak Transmission Loss= 240

Peak Transmission Loss= 375

Figure 4.16: The 2 structures showing the highest and most consistent transmission loss values

If we were to look at the two prior models and their respective graphs we would find that the overall transmission loss that is attained through use of the two ring coaxial ring mass model is much higher. So to maximize the transmission loss that we attain from the structures chosen for use during the construction of an acoustic barrier, using the polyethylene model appears to be the best choice.

Not only that but the use of the polyethylene model appears to be largely congruent with our stated goal of using a material that is easy to acquire and manufacture for the purposes of using as a metamaterial, so the findings of the simulation stage of the research appear to thus far be favorable.

4.4 Limitations:

As was stated before one of the big challenges to getting an accurate simulation of the transmission loss are the limitations faced inherently when being reliant on the use of a model. Three of the big limiting factors that are not accounted for when using this model are:

1. Heat transfer: When the wave hits the material there is some energy loss due to the wave energy being converted to heat energy and being dissipated across the structure. This is not accounted for when using the acoustics module of the simulation software.

2. Elastic Properties of material: In practical use, the material that is used will not be stiff and inelastic but rather will display movement and deformation when hit by the sound waves. This also causes a loss of energy that is not accounted for.

3. Wave reflection: As the wave hits the material some of it is reflected off and interferes with the incoming propagation. This results in a further decrease in the transmission loss as there is a potential decrease in the incident wave itself. For our simulation however, we model the incident wave power as being constant and therefore we cannot account for this phenomenon.

CHAPTER 5: APPLICATIONS

Acoustic metamaterials have the ability to modify and control sound waves in ways that traditional materials cannot. Metamaterials with a refractive index of zero or even negative for sound provide up exciting options for acoustic surveillance and sound management at subwavelength scales. The employment of transformation acoustics theory with highly anisotropic acoustic metamaterials allows for exact control of sound field deformation, which can be utilized to hide or cloak objects from incident acoustic radiation, for example. Acoustic metamaterials provide useful material properties that can be easily operated, which are impossible to do with ordinary materials. As a result, hitherto unthinkable applications could now be accomplished. Acoustic metamaterials can be used in various devices and applications. We chose a way of design that helps us make basic unit cells out of solid inclusions in a background fluid. The useful materials properties of mass density and bulk modulus are present in these unit cells.

5.1 Sound insulation in Buildings:

The capability of construction materials to reduce sound transmission along a partition is known as sound insulation. When the sound insulation of a decent traditional office building project is in the range of 45dB, it is considered good. This value can be explained in the following manner. If the room produces a 65dB sound, the sound is received at 20dB by the receiver in the neighboring room. This is a whisper value. If the volume is increased to 75 dB (a raised voice), the sound levels in the neighboring room will be 30 dB (clearly heard). It's important to remember that sound insulation refers to how much sound is lost rather than how much sound is returned to the space. The undesirable and unexpected sound is always considered a noise, and this is a matter of the building's acoustic properties.

Figure 5.1: Sound insulation system in a building.

Source of figure 5.1: https://theconstructor.org/building/acoustic-properties-building-materials/14449/

5.2 Acoustics of Audio Recording Room:

Although studios can be enormous rooms, the vast majority of studios now under construction have a total area of less than 200 square meters for the tone hall and control room. Mega-studios are no longer necessary; current recording equipment that enables for high-quality audio recording now fits in two bags. Simultaneously, the physical laws of sound propagation in rooms have remained constant.

Audio Recording Studio Acoustics The hall and control room must have the essential, distinct acoustic design for a studio to generate a typically high and realistic product.

First, regardless of their modest size, these rooms should have no trouble recording and reproducing low frequencies. In the case of a tone hall, low-frequency issues will prevent you from properly recording instruments that "play low frequencies," such as drums or basses. An unmanageable bass in the control room will make the studio's soundtrack seem entirely strange in all other places. That is why, when building studios, far more attention is given to the design and proportions of the space, and after sound insulation work is completed, a substantial amount of time is spent to adjusting the sound field at low frequencies.

There are other criteria for sound-absorbing and sound-scattering materials in a control room, depending on the destination (stereo or multichannel sound recording). It's vital to remember that if a place has its own distinct sound, the techniques blended there may sound very different in other spaces. As a result, providing a neutral acoustic environment within the premises is one of the most prevalent approaches of arranging control rooms. The necessity for invariance (flat characteristic) across the full frequency range is paired with a short bounce period.

Figure 5.2: Acoustic system in Audio recording room

Source of figure 5.2: https://www.acoustic-group.com/solutions/recording/audio_recording/

5.3 Acoustic Auditorium:

Superior ⑳ sound quality for voice and music is required in auditoriums, with clear tones and purity of sound reaching every person of the sitting audiences. ② Most auditoriums are constructed with non-parallel sets of perimeter walls, sloped ceilings, and tilted floors to equally spread sound wave reflections across the room. A lack of attenuation causes poor room acoustics, resulting in echoes in the room that combine to muddy unique sound impulses. Speech sharpness and musical harmony are weakened, leaving the listener straining to hear.

The purpose of improving the ⑳ sound quality in your Auditorium is to provide superior sound to everyone, ㊲ regardless of their seating location. The ⑦ background noise in the Auditorium can be cleansed by installing a set of Auditorium acoustic panels on the perimeter wall or ceiling surfaces. As the echoes are collected and recorded, the initial sound becomes clearer.

5.4 Acoustics and Interior Design:

Acoustics in architecture is both an art and a science. Interior acoustics are just as significant as those in public settings. Acoustic values must be considered both during construction and during interior design and decoration. Surprisingly, but understandably, most of us only realize this after we've moved in. This increases the importance of interior designers' work while also making it more sophisticated and difficult.

Any interior should have the same sound quality as it does appearance. As we work or live there, it should be nice to the eyes as well as the hearing. The function of architectural acoustics in achieving this and providing a pleasurable experience is critical.

Figure 5.4: Acoustic system for interior design

Source of figure 5.4: ㉖ https://www.gyptechsystems.com/blog/2018/03/acoustics-and-interior-design/

CHAPTER 6: CONCLUSIONS

Based on the transmission loss graphs obtained above it is clear that in terms of materials polyethylene appears to be the best one for the purpose of noise reduction. As such, based on the findings of our simulations we can recommend its use for the purposes of constructing a metamaterial that will be used for noise reduction. As stated before there were a few factors that were limiting the accuracy of the simulations that we had run but we will be accounting for them via experimental validation and further research that will be using more sophisticated methods of simulation, such as the incorporation of acoustic-structure interaction that will give us a clearer picture of the changes induced within the propagation wave.

As stated previously one of the future goals of this research is to empirically verify its findings through the use of physical experimentation. There has already been steps taken to ensure access to the proper equipment and facilities to carry out the experiment that we intend to conduct.

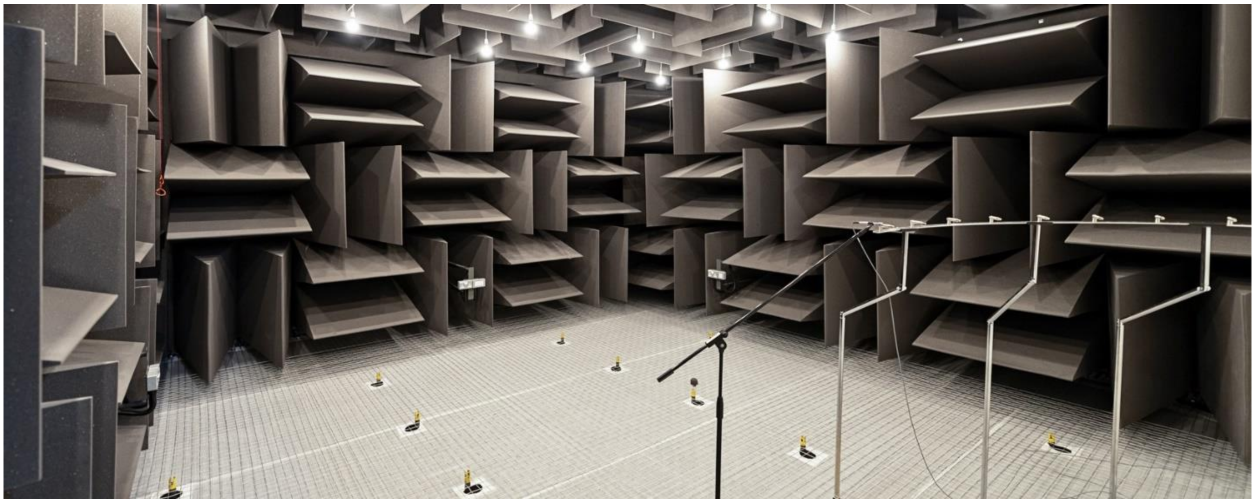


Figure 6.1: An acoustics chamber similar to the one we intend to use for experimental validation. [16]

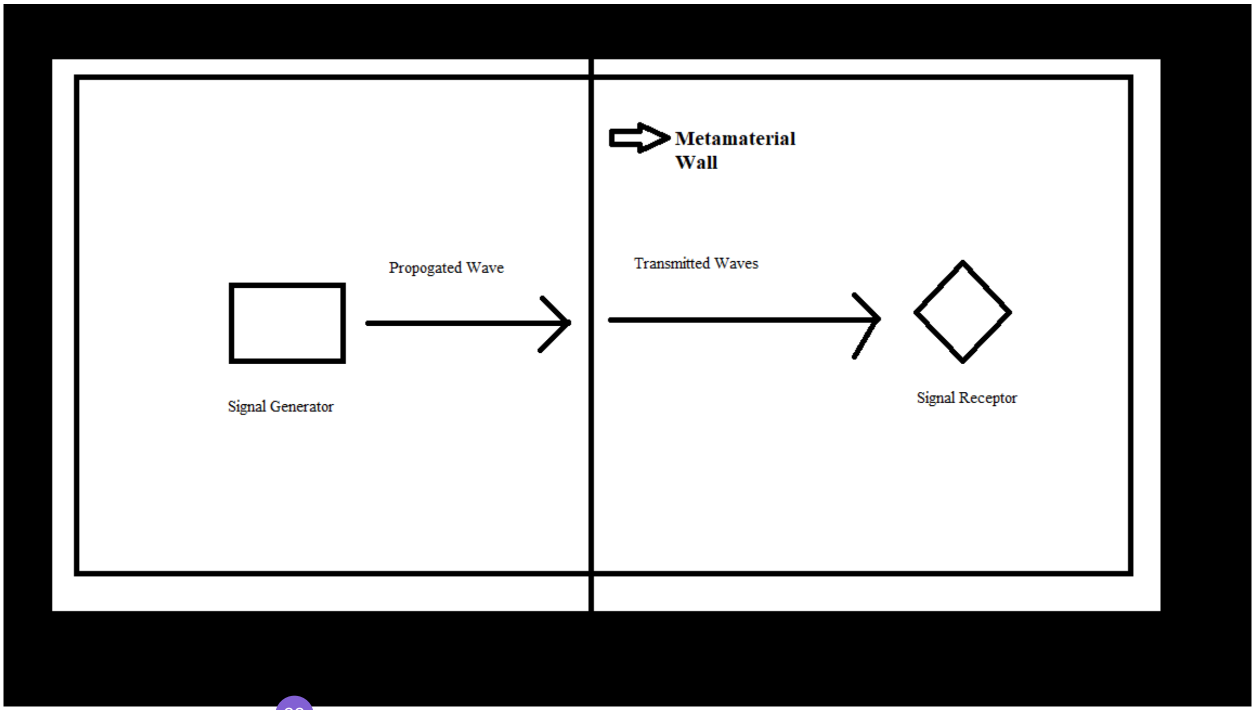


Figure 6.2: Simplified Schematic Diagram of the experimental setup used for our research

As shown in the diagram above the experimental setup that we will be using will be comprised of using a signal generator to fire a sine wave of specific frequencies at a metamaterial wall and then using a signal receiver to analyze how the frequency of the wave changes as it goes through the wall. A graph of the transmission loss against the frequency will be generated similar to the simulations and their results compared.

We believe that carrying out this research is important as the potential uses of this technology are far-reaching and beneficial. Through the refinement of the design and simulation techniques highlighted in this paper we hope to eventually make the technology that has been used in this research viable for implementation within workplaces and other appropriate venues sometime in the near future.

Bibliography

[1] E. L. D.E. Broadbent, "Effects of Noise Reduction in a Work Situation," *Occupational Psychology,* vol. 34, no. 2, pp. 133-40, 1960.

[2] Z. Z. X. G. B. C. H. H. Nansha Gao, "Acoustic Metamaterials for Noise Reduction: A Review," 29 January 2022.

[3] J. Brennan, "Sciencing," 30 April 2018. [Online]. Available: https://sciencing.com/limitations-models-science-8652502.html. [Accessed 05 May 2022].

[4] C.-M. C. G. M. S. N. Christina J. Naify, "Transmission loss of membrane-type acoustic metamaterials with coaxial ring masses," *Journal of Applied Physics,* 2011.

[5] H. H. J. H. W. Nansha Gao, "A composite and deformable honeycomb acoustic metamaterial," *World Scientific,* vol. 32, no. 20, 2018.

[6] J. C. A. A. Steven A.Cummer, "Controlling sound with acoustic metamaterials," *Nature reviews materials,* 2016.

[7] CAL POLY AUDIO ENGINEERING SOCIETY, "CAL POLY AUDIO ENGINEERING SOCIETY," 2021. [Online]. Available: https://www.calpolyaudio.club/acoustic-metamaterials. [Accessed 06 May 2022].

[8] P. B, "Sound Assured," [Online]. Available: https://www.soundassured.com/blogs/blog/what-is-transmission-loss-of-sound. [Accessed 06th May 2022].

[9] S. MacDonald, "SIEMENS," 23 October 2019. [Online]. Available: https://community.sw.siemens.com/s/article/sound-transmission-loss. [Accessed 06 May 2022].

[10] The world material, "The World Material," [Online]. Available: https://www.theworldmaterial.com/what-is-18-8-stainless-steel/. [Accessed May 2022].

[11] COMSOL, "COMSOL," [Online]. Available: https://www.comsol.com/acoustics-module. [Accessed 06 May 2022].

[12] Britannica, "Britannica," [Online]. Available: https://www.britannica.com/science/speed-of-sound-physics. [Accessed 07 May 2022].

[13] Britannica, "Britannica," [Online]. Available: https://www.britannica.com/science/atmospheric-pressure. [Accessed 07 May 2022].

[14] COMSOL, "COMSOL," [Online]. Available: https://www.comsol.com/model/absorptive-muffler-1367. [Accessed 08 May 2022].

[15] Libretexts, "Physics: Libretexts," 08 March 2022. [Online]. Available: https://phys.libretexts.org/Bookshelves/University_Physics/. [Accessed 08 May 2022].

[16] Anechoic Chambers, "Anechoic Chambers," May 2022. [Online]. Available: https://www.iacacoustics.global/anechoic-chambers/.

{18] X. Ziang, "Encyclopedia Britannica," May 2022. [Online]. Available: https://www.britannica.com/topic/metamaterial.

[19] Merriam Webster, "Merriam Webstaer," May 2022. [Online]. Available: https://www.merriam-webster.com/dictionary/transmission%20loss.

[20] R. E. Berg, "Encyclopedia Britannica," May 2022. [Online]. Available: https://www.britannica.com/science/acoustics.

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