A Characterization and Prediction of Acoustical Properties in Sound Package Materials

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Outline

- Introduction
- Theoretical Background for Sound Package Materials
- Transfer Matrix Techniques (TMM)
- Introduction to Intrinsic Biot Parameters
- Sound Absorption Coefficient - Theory and Measurement
- Sound Transmission Loss - Theory and Measurement
- Inverse Characterization Techniques
- Sound Absorption Coefficient-Simuation and Validation
- Sound Transmission Loss-Simuation and Validation
- Design of Vehicle Dash Insulator
- Conclusions

Introduction to Porous Materials

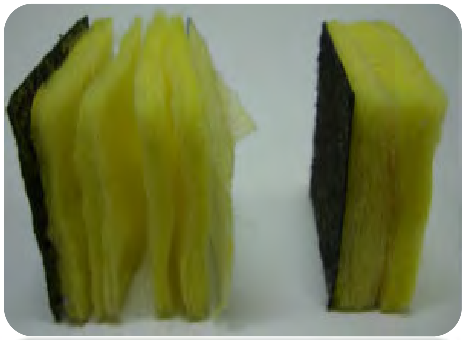
- Poroelastic Materials

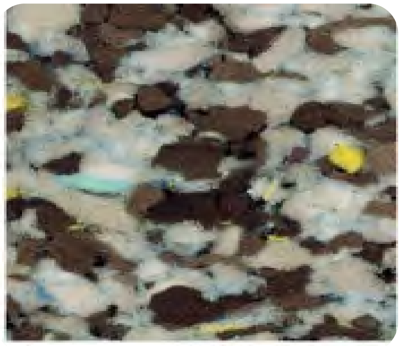
  e.g. Melamine, Polyurethane

- Fibrous Materials-

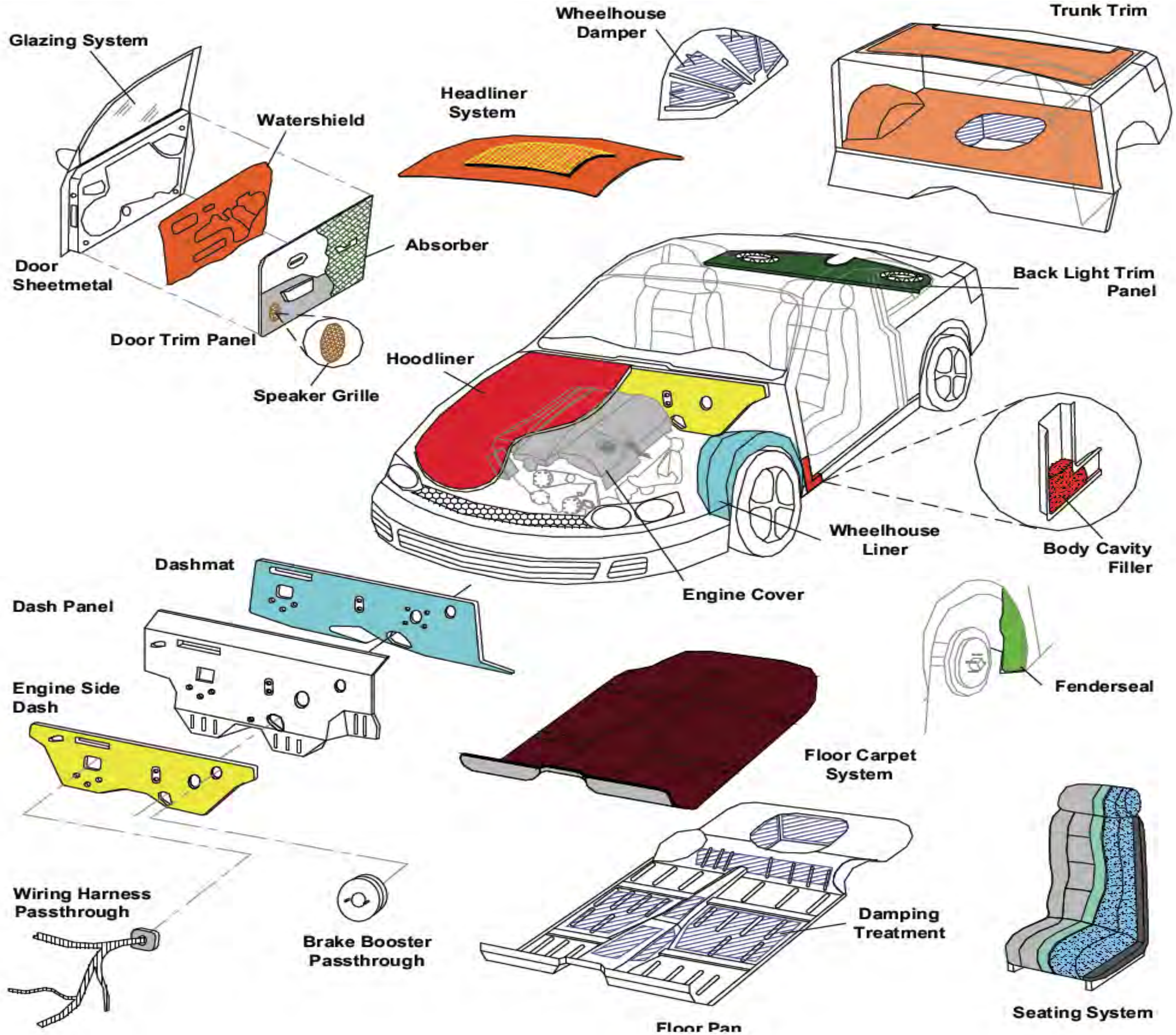
  e.g. Glass Wool, Fiberform

- Felts (Recycled Materials)- e.g. Nonwovens, PET Felts
- Resistive Films/ Scrims
- Aluminium, Polythelyne films
- Micro-perforate Materials





Sound Package Materials-Automotive Applications



Sound Absorbing Porous Materials - Classification

Sound Absorbing Porous materials are classified in three categories

- **Elastic Frame**
  - Full coupling between the fluid and structural phases of the material
  - Motion of both fluid and frame
  - Frame bulk modulus of same order as fluid (approx. 100000 Pa for air)
  - Dilatational fluid and frame wave propagation, as well as frame shear wave propagation (3 wave types)
- **Rigid Frame**
  - Solid phase does not move
  - Frame bulk modulus is significantly greater than that of the fluid
  - Airborne wave only, i.e. situations where the frame is not excited directly
  - Boundary conditions are important
- **Limp Frame**
  - Solid phase has essentially no stiffness, moves in phase with the acoustic wave
  - Frame bulk modulus significantly less than that of air
  - Airborne wave propagation only
  - Boundary conditions less important

Poroelastic Model-Elastic Frame (Biot Model)

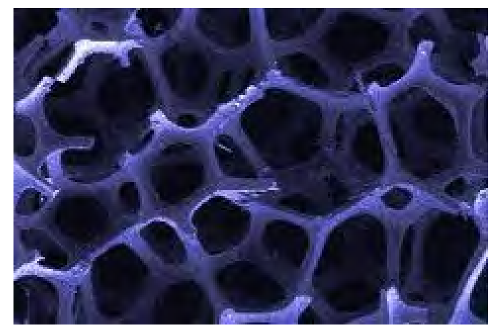
- Biot's theory describes the interactions between the 2 phases :

  Solid phase = elastic skeleton or frame

  Fluid phase = air (or other fluid) in the pores

$$\tilde{\mu} u_{i,jj} + \left(\tilde{\lambda} + \tilde{\mu}\right) u_{i,jj} + \omega^2 \tilde{\rho}_s u_i = -\tilde{\gamma}\, p_i$$ Elastodynamic Equation

$$\frac{1}{\omega^2 \tilde{\rho}_f} p_{ii} + \frac{1}{\tilde{K}_f} p = -\tilde{\gamma} u_{i,i}$$ Helmholtz Equation



u Solid phase macroscopic displacement vectors

p Fluid phase macroscopic pressure

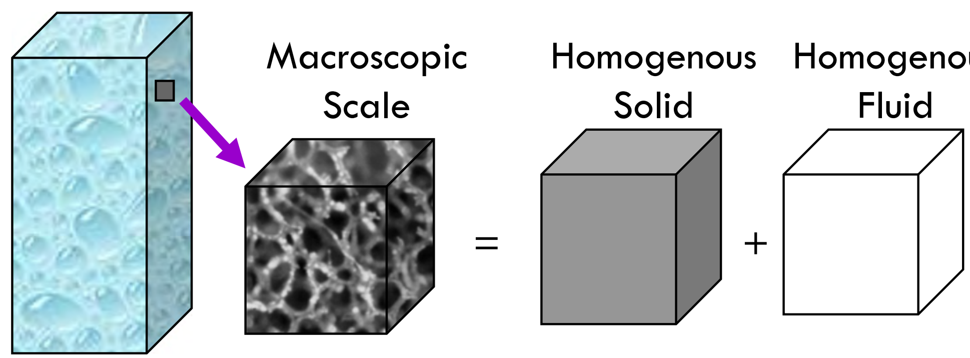
λ, μ Effective solid phase Lame' Cofficients

K_f Effective fluid phase bulk modulus

ρ_s Effective solid phase density

ρ_f Effective fluid phase density

γ Effective fluid-solid coupling coefficient



Poroelastic Model-Rigid Frame

$$\rho_c = \frac{\alpha_\infty \rho_0}{\phi} + \frac{\sigma}{i\omega}\sqrt{1 + \frac{4i\alpha_\infty{}^2 \eta \rho_0 \omega}{\sigma^2 \Lambda^2 \phi^2}}$$

Viscous Effects

$$K_c = \frac{\kappa \cdot P_0 / \phi}{\kappa - (\kappa - 1)\left[1 + \frac{8\eta}{i\rho_0 \omega N_p \Lambda'^2}\sqrt{1 + \frac{i\rho_0 \omega N_p \Lambda'^2}{16\eta}}\right]^{-1}}$$

Thermal Effects

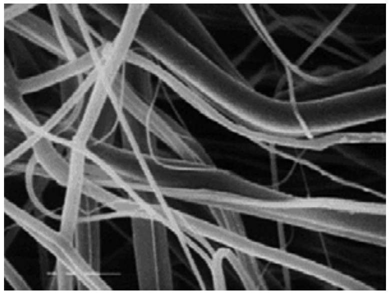
Poroelastic Model- Limp Frame

- Helmholtz Equation with effective density and bulk modulus
- Added Inertia for solid phase

$$\rho_c' = \frac{\rho_c M - \rho_0{}^2}{M + \rho_c - 2\rho_0}$$

Viscous Effects

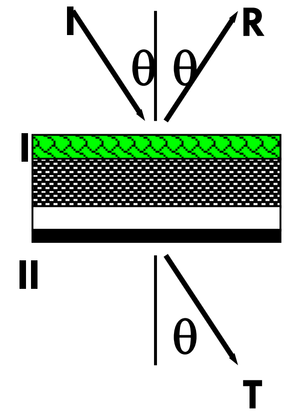
with $M = \rho_1 + \phi\rho_0$



Transfer Matrix Approach

Transfer Matrix for single layer

$$\begin{bmatrix} P_n \\ V_n \end{bmatrix} = \begin{bmatrix} T_1 \end{bmatrix} \begin{bmatrix} P_{n+1} \\ V_{n+1} \end{bmatrix}$$



$$\begin{bmatrix} T_1 \end{bmatrix} = \begin{bmatrix} \cos(k_c.d) & {}^{j}\!/\!_{z_c}.\sin(k_c.d) \\ j\,z_c.\sin(k_c.d) & \cos(k_c.d) \end{bmatrix}$$

$$Z_c = \sqrt{\rho_c \cdot K_c} \quad [\mathrm{Ns/m^3}]$$

$$k_c = \omega\sqrt{\rho_c / K_c} \quad [\mathrm{m^{-1}}]$$

Reflection Coefficient

$$R = \frac{T_{11} - \rho_0 c T_{21}}{T_{11} + \rho_0 c T_{21}}$$

Transmission Coefficient

$$T = \frac{2e^{ikd}}{T_{11} + \frac{T_{12}}{\rho_0 c} + \rho_0 c T_{21} + T_{22}}$$

- Normal Incidence Sound Absorption Coefficient $\alpha = 1 - |R|^2$
- Normal Incidence Sound Transmission Loss $STL = 10\log\left(\frac{1}{|T|^2}\right) \quad [dB]$
- Random Incidence Sound Absorption Coefficient $\alpha_{random} = \int_{\theta_{min}}^{\theta_{max}} \alpha(\theta)\cos\theta\sin\theta d\theta$
- Random Incidence Sound Transmission Loss

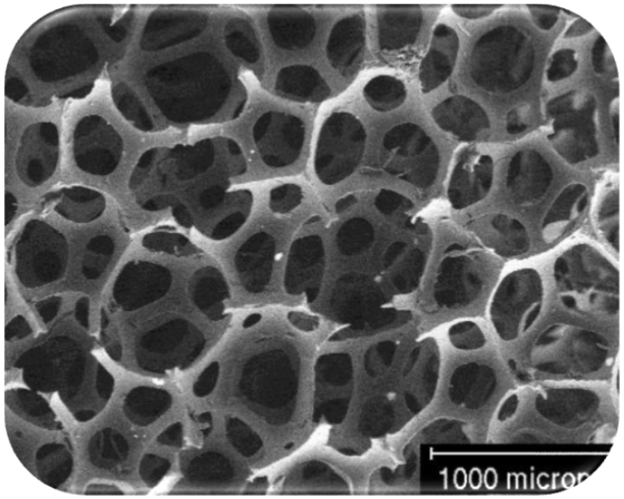
$$\tau(\theta) = \int_{\theta_{min}}^{\theta_{max}} |T(\theta)|^2 \cos\theta\sin\theta d\theta$$

$$RSTL = 10\log\left(\frac{1}{\tau(\theta)}\right) \quad [dB]$$

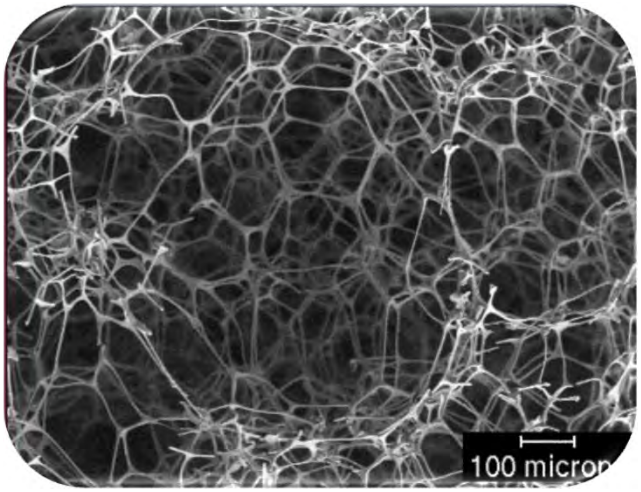
Poroelastic Materials-Characterization

Biot's Parameters for Porous Materials

- Porosity ϕ
- Air-flow resistivity σ
- Tortuosity α_{∞}
- Characteristic Lengths Λ & Λ'
- Density of Fibers/Material ρ
- Young modulus E
- Poisson Ratio ν
- Loss factor η



Polyurethane foam

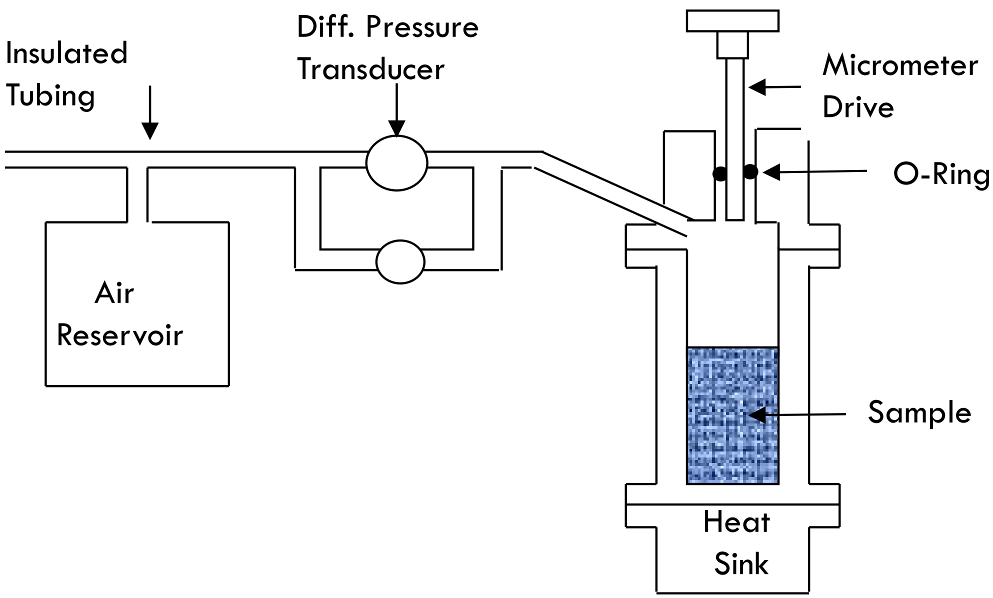


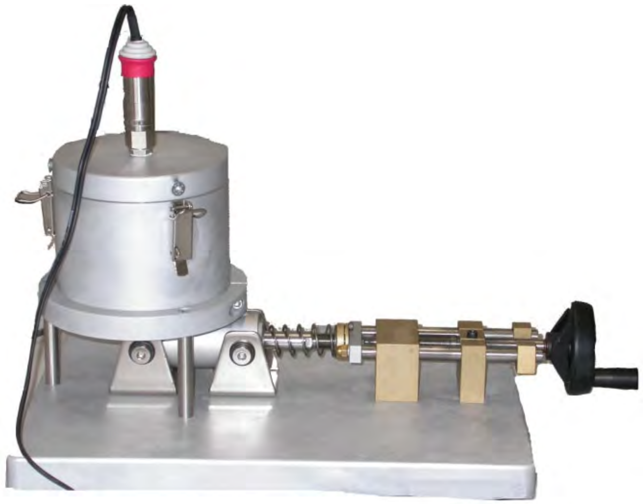
Melamine foam

Porosity

- It is the ratio of the volume of air voids to total volume of material

Open Porosity $$\phi = \frac{V_{air}}{V_{total}}$$

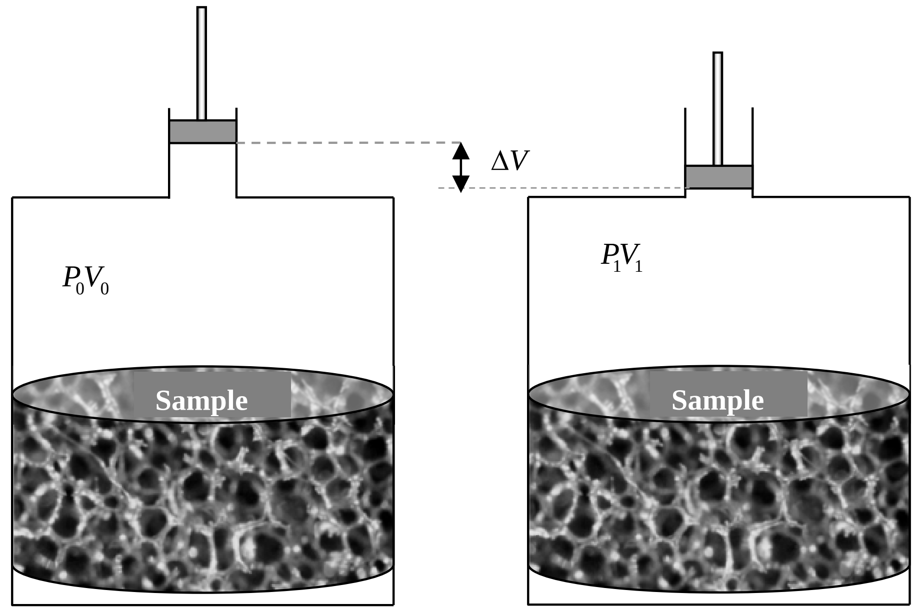




Range $0 \le \phi \le 1$

Measurement Principle

- It is based on Isothermal Expansion of ideal gas (Boyle's law)

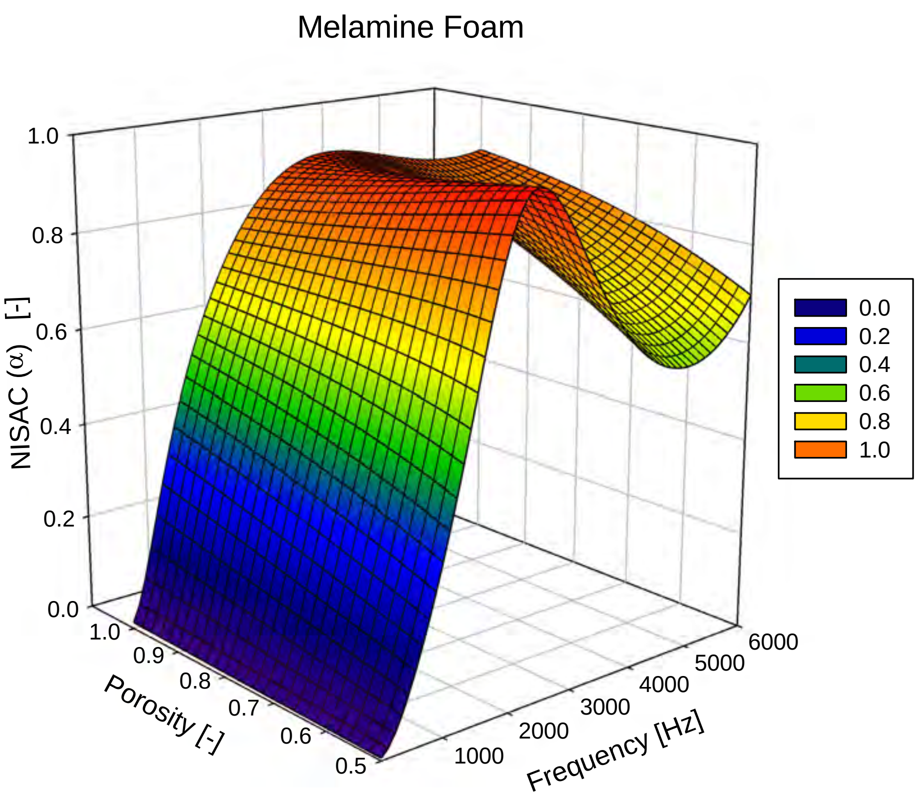


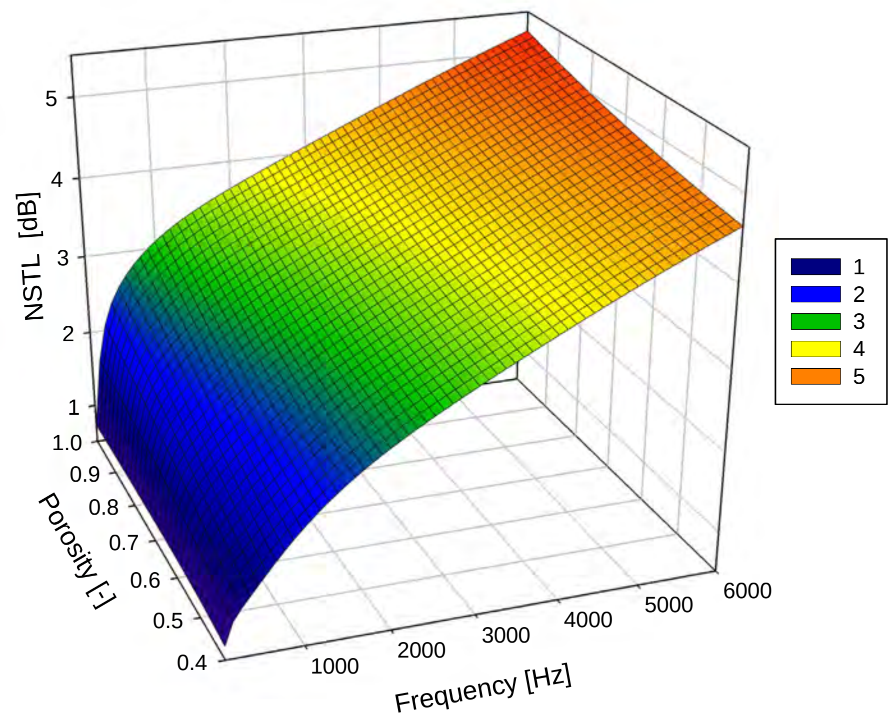
- Results for some porous materials

Melamine Foam	0.99
Cellular Rubber	0.84
Coustone	0.46

$$\phi = 1 - \left[\frac{V_{chamber} - \frac{P_1}{P_1 - P_0}\Delta V}{V_{sample}} \right]$$

Effect of Porosity on Sound Absorption and Transmission Loss





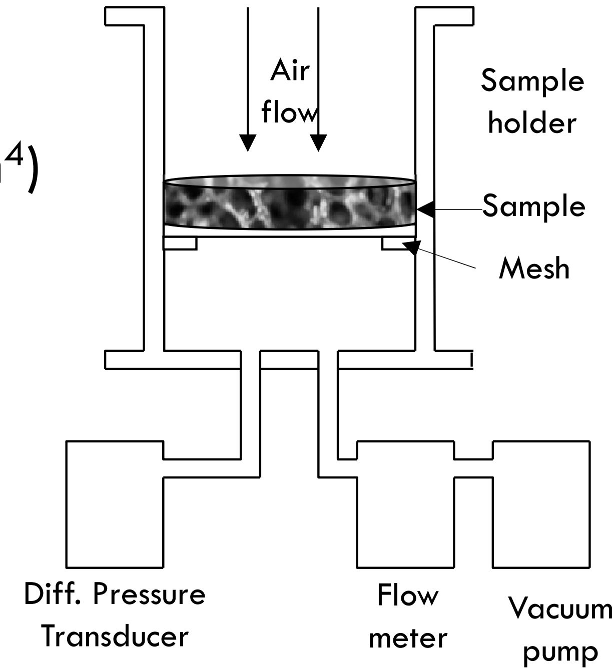
Porosity Variation- 0.5 to 1,

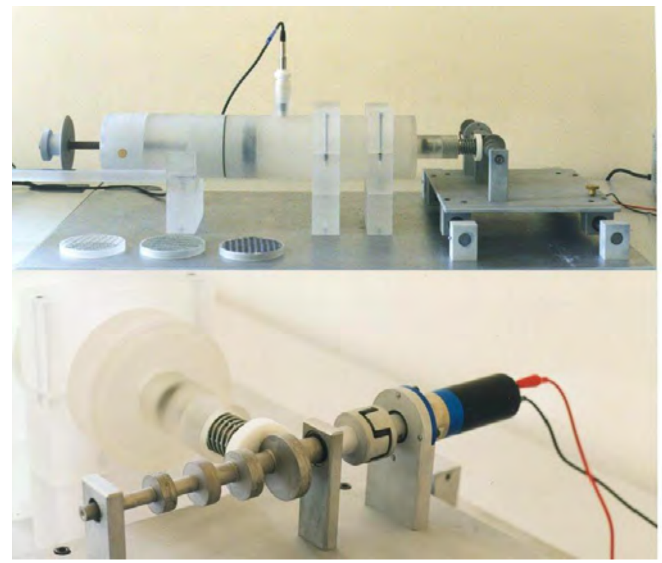
Flow Resistivity 10872, tortuosity 1, VCL 99 and TCL 142

Flow Resistivity

- It is the ratio of Air pressure difference to steady state velocity

$$\sigma = \frac{\Delta P}{V.d} \quad (Ns/m^4)$$



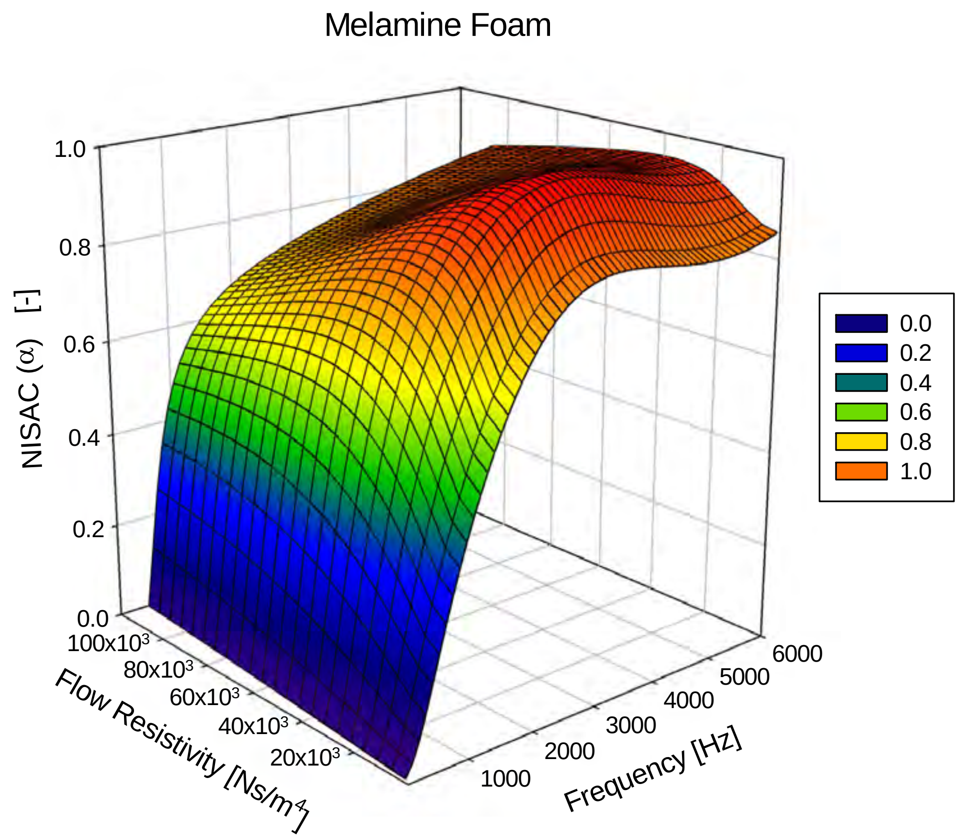


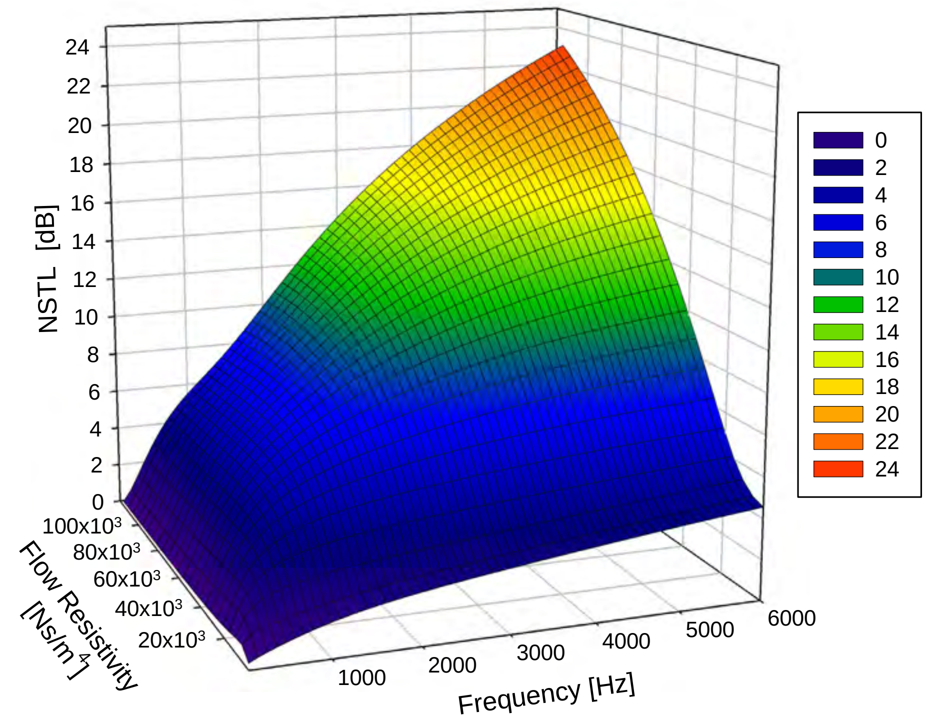
Range $10^3 < \sigma < 10^6$

- Results for some Typical Materials

Melamine Foam	10872
Cellular Rubber	150388
Coustone	34056

Effect of Flow Resistivity on Sound Absorption and Transmission Loss



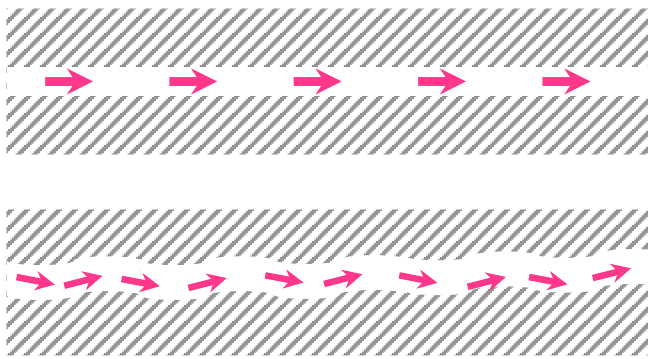


Flow Resistivity Variation- 1000-100000

Porosity 0.99, tortuosity 1, VCL 99 and TCL 142

Tortuosity (Structure Factor)

- Tortuosity parameter describes the degree of irregularity of the porous "flow channels"
- Dimensionless Parameter
- Tortuosity range for Porous materials $1 < \alpha_\infty < 10$



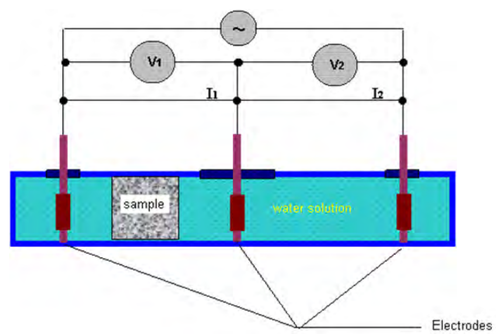
$\alpha_\infty = 1$

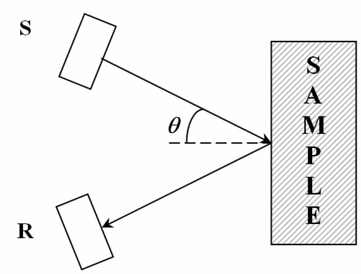
$\alpha_\infty > 1$

- Methods

  - Conductivity Method [Brown *et. al*]

  - Oblique incidence [Fellah *et. al*]





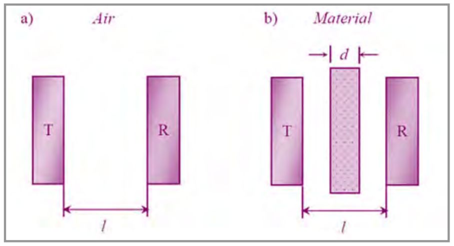
Measurement Principle

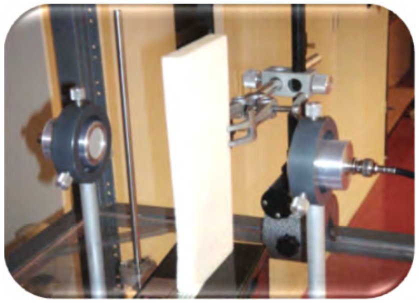
- High frequency limit of the complex phase velocity

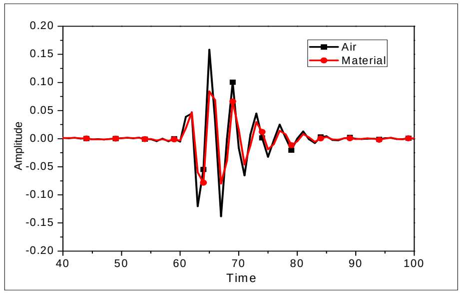
$$c = \frac{c_0}{\sqrt{\alpha_\infty}}(1-\varphi) \qquad \alpha_\infty\big|_\omega = \left(\frac{c_0}{c}\right)^2 (1-\varphi)^2$$

$$\lim_{\omega \to \infty} \varphi = 0$$

$$\alpha_\infty = \left\{ \lim_{\omega^{-1/2} \to 0} \left(\frac{c_0}{c}\right) \right\}^2 \geq 1$$

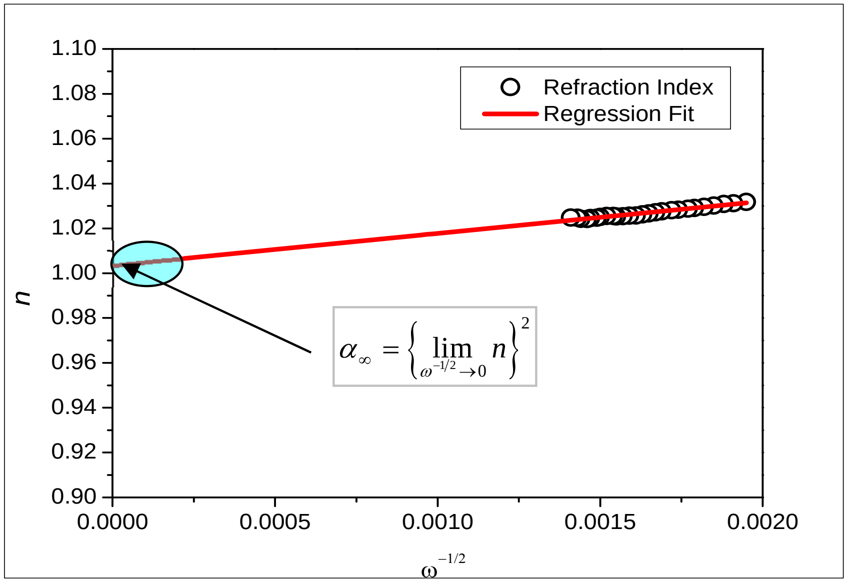




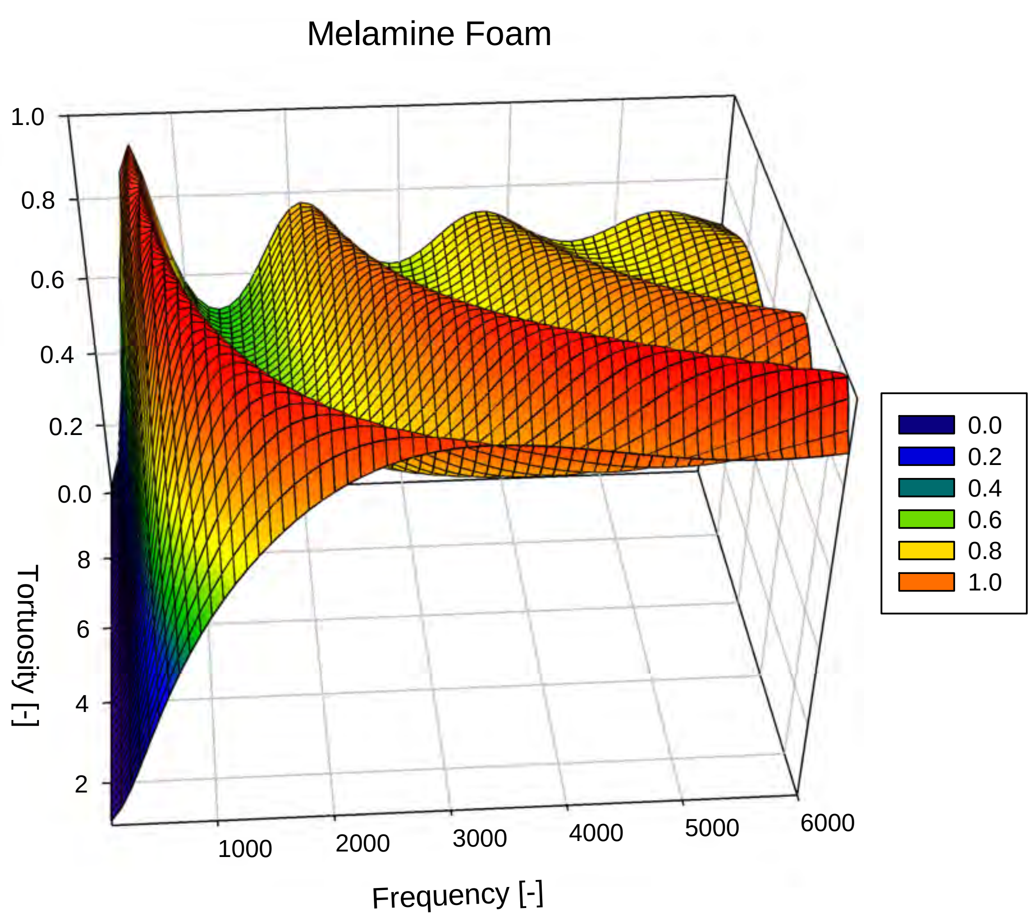


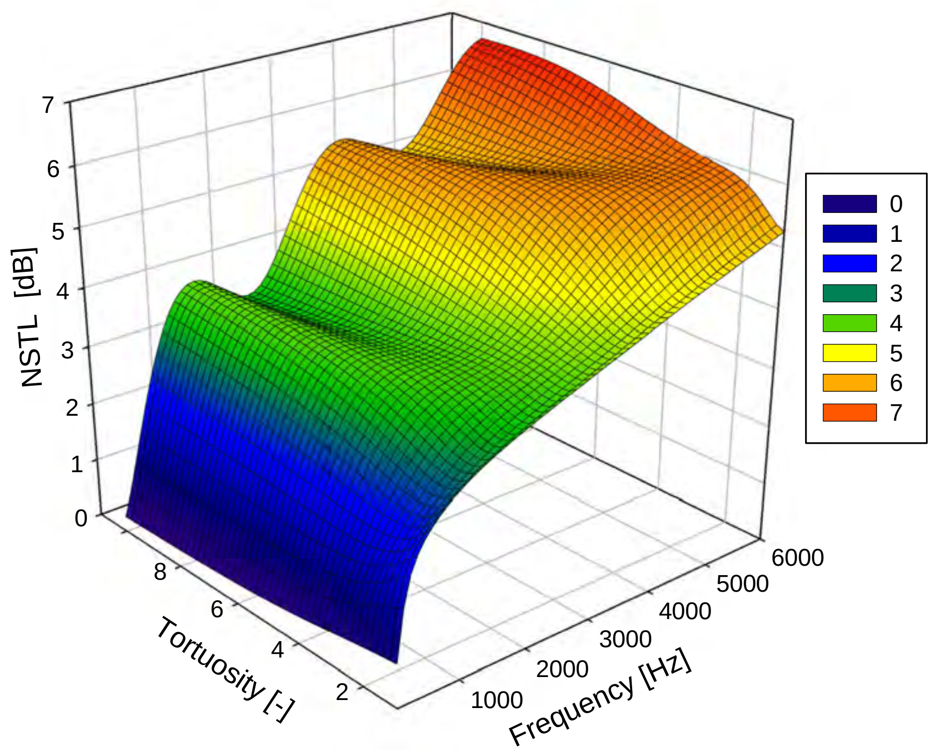
- Results for some Typical Materials

Melamine Foam	1.002
Cellular Rubber	2.97
Coustone	1.96



Effect of Tortuosity on Sound Absorption and Transmission Loss





Tortuosity Variation- 1-10

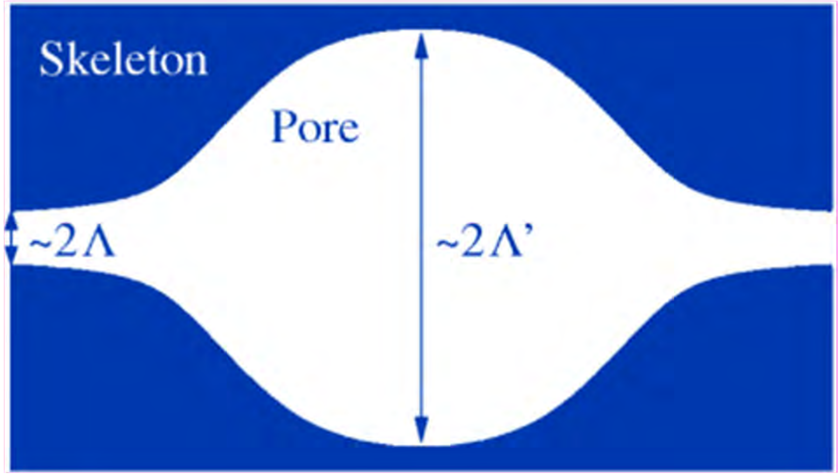
Porosity 0.99, FR 10872, VCL 99 and TCL 142

Chracteristics Lengths (VCL& TCL)

- **Viscous Characteristic Length**

  It is related to the size of the inter-connection between two pores in the porous material

$$\frac{2}{\Lambda} = \frac{\int_A v^2(r_w)\,dA}{\int_V v^2(r)\,dV}$$

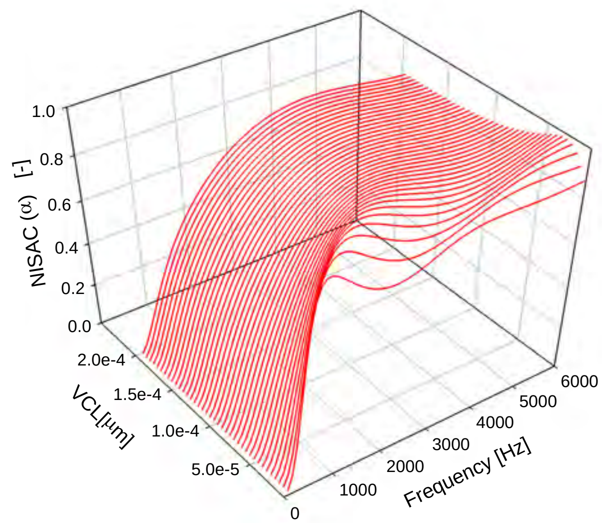


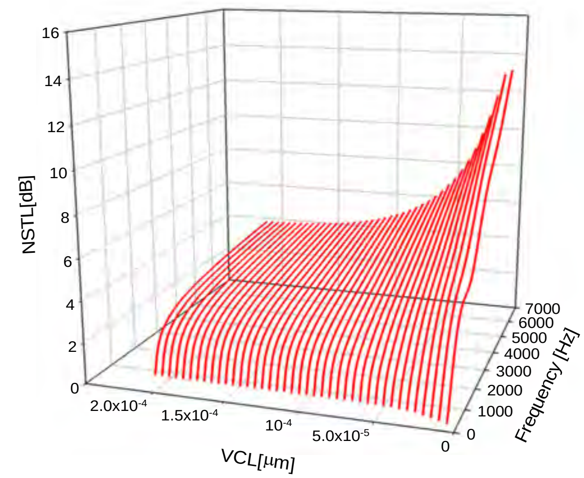
- **Thermal Characteristic Length**

  It is related to the diameter of the pore connecting chanels

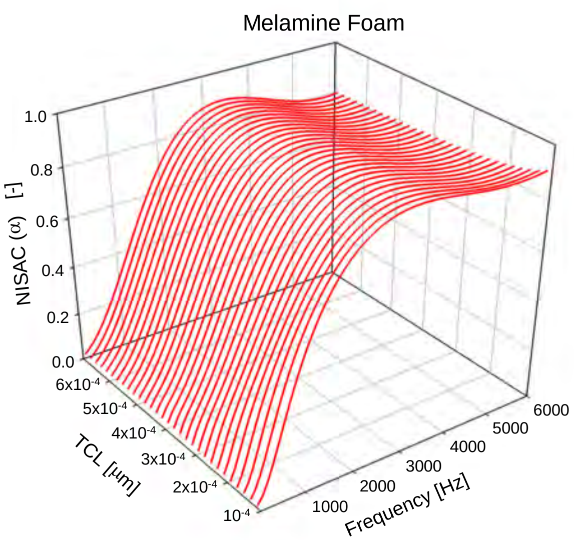
$$\frac{2}{\Lambda'} = \frac{\int_A dA}{\int_V dV}$$

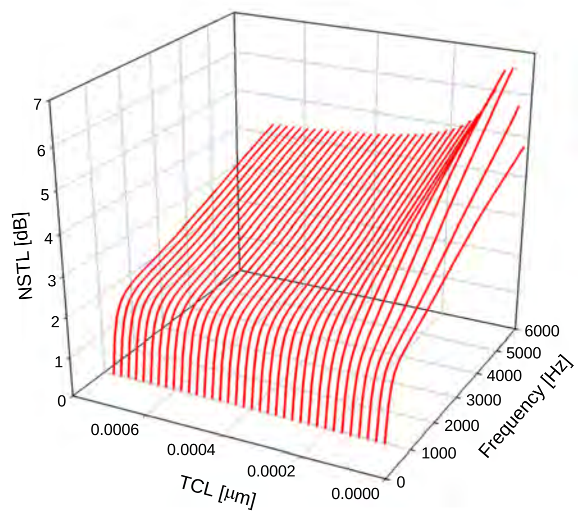
Effect of VCL & TCL on Sound Absorption and Transmission Loss





VCL Variation-
1 - 200 micron

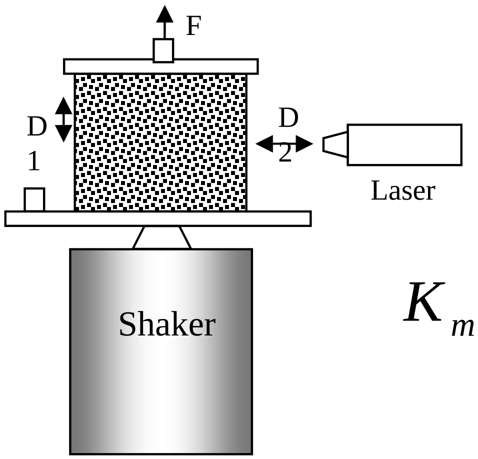




TCL Variation-
1 - 700 micron

Porosity 0.99, FR 10872, Tortuosity 1.001

Mechanical Parameters-Young's Modulus, Poisson Ratio & Loss Factor



$$T = \mathrm{Re}\left\{\frac{D_1}{D_2}\right\}$$

$$K_m = \mathrm{Re}\{Z\} = \mathrm{Re}\left\{\frac{F}{D_2}\right\}$$

$$\mathrm{Im}\{Z\} = \mathrm{Im}\left\{\frac{F}{D_2}\right\}$$

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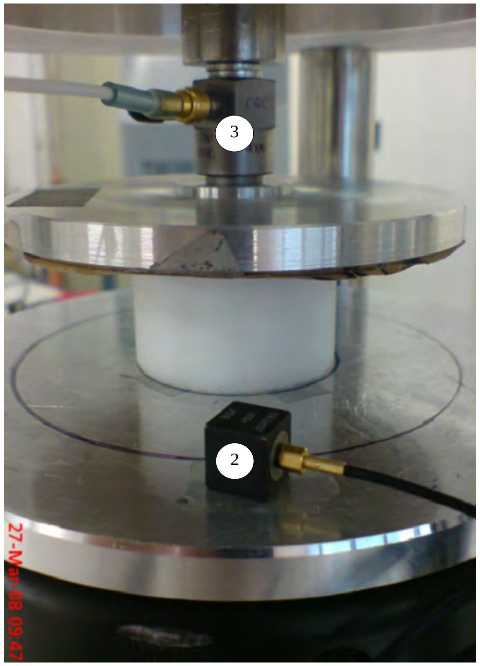
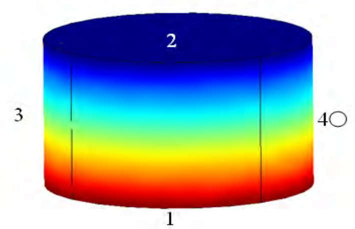
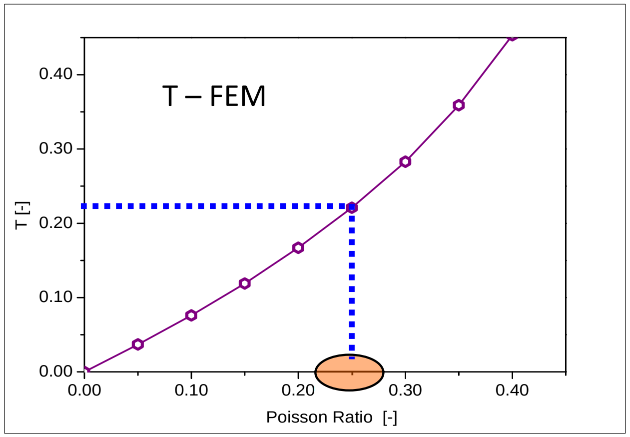
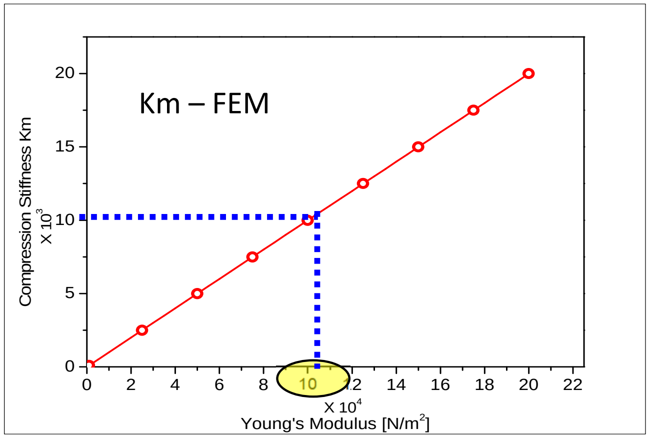




Quasi-static
Mechanical Analyzer

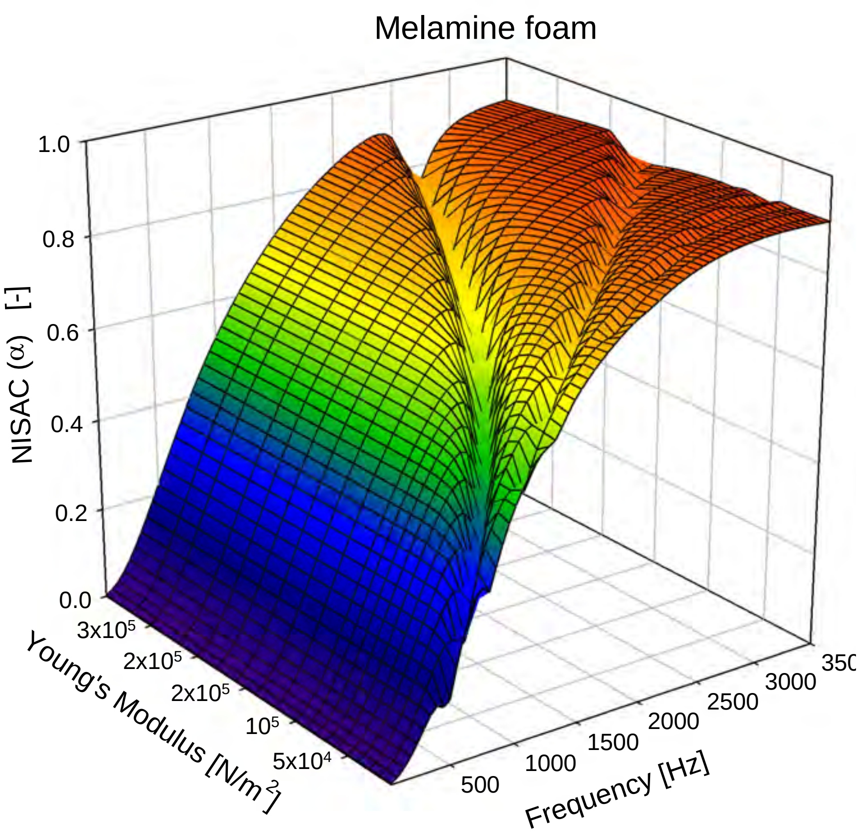


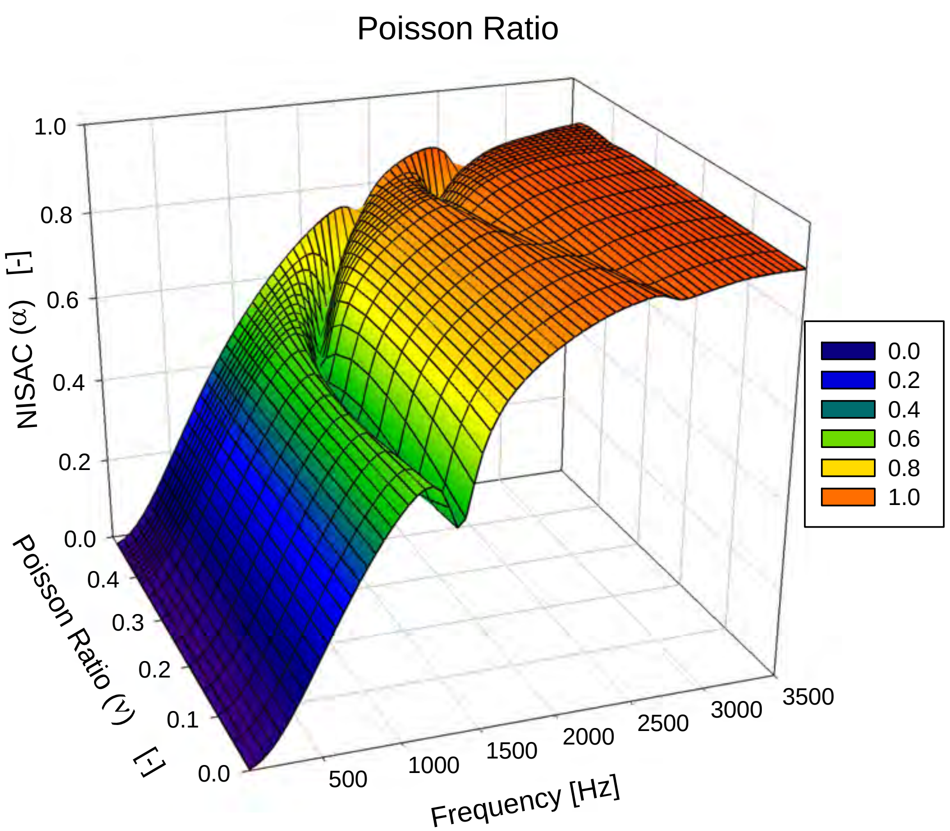


Results-Melamine Foam

Young's Modulus	80000
Poisson Ratio	0.28
Loss Factor	0.07

Effect of Young's Modulus and Poisson Ratio on Sound Absorption and Transmission loss



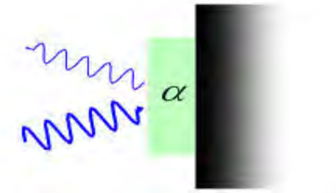


E -Variation 10000 -300000 Pa

ν -Variation 0.01-0.48

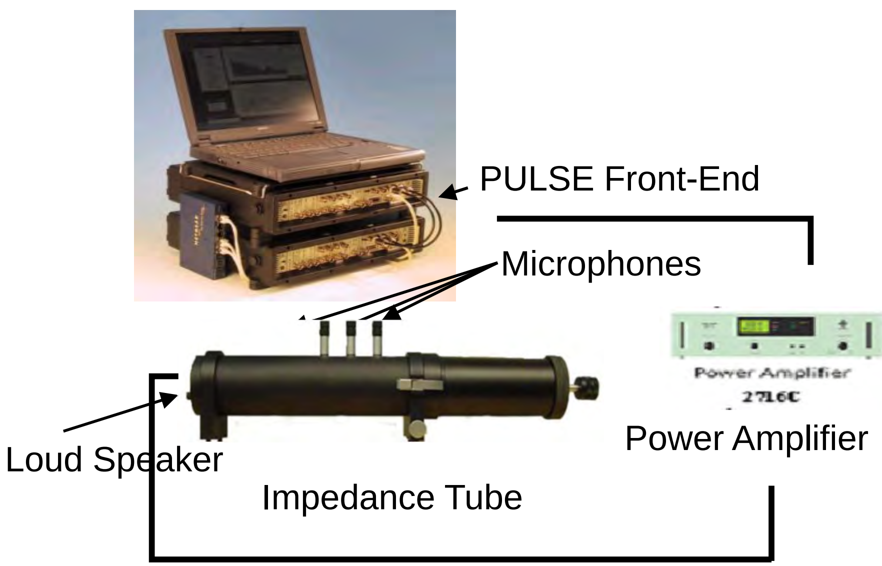
Porosity 0.99, FR 10872,
Tortuosity 1.001, VCL 99 and TCL 142

Sound Absorption



- It is defined as the ratio of the sound energy reflected by a surface to the sound energy incident upon that surface.
- The sound absorption coefficient ranges from 0 to 1 and varies with frequency.

$$\alpha = \frac{Sound\ energy\ reflected}{Sound\ energy\ incident} \qquad [-]$$



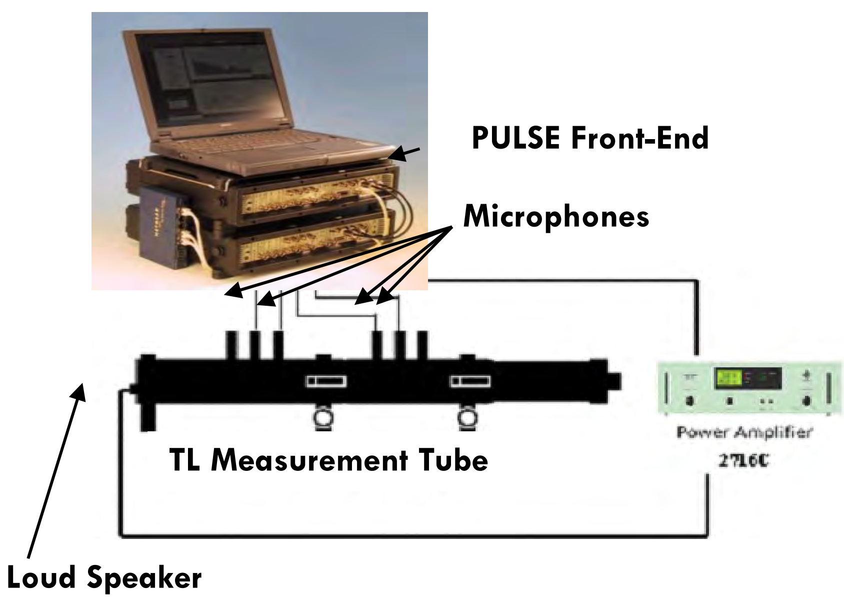
Sound absorption Coefficient Measurement in Two Impedance Tube

Random Incidence Sound Absorption in a Reverberation Room

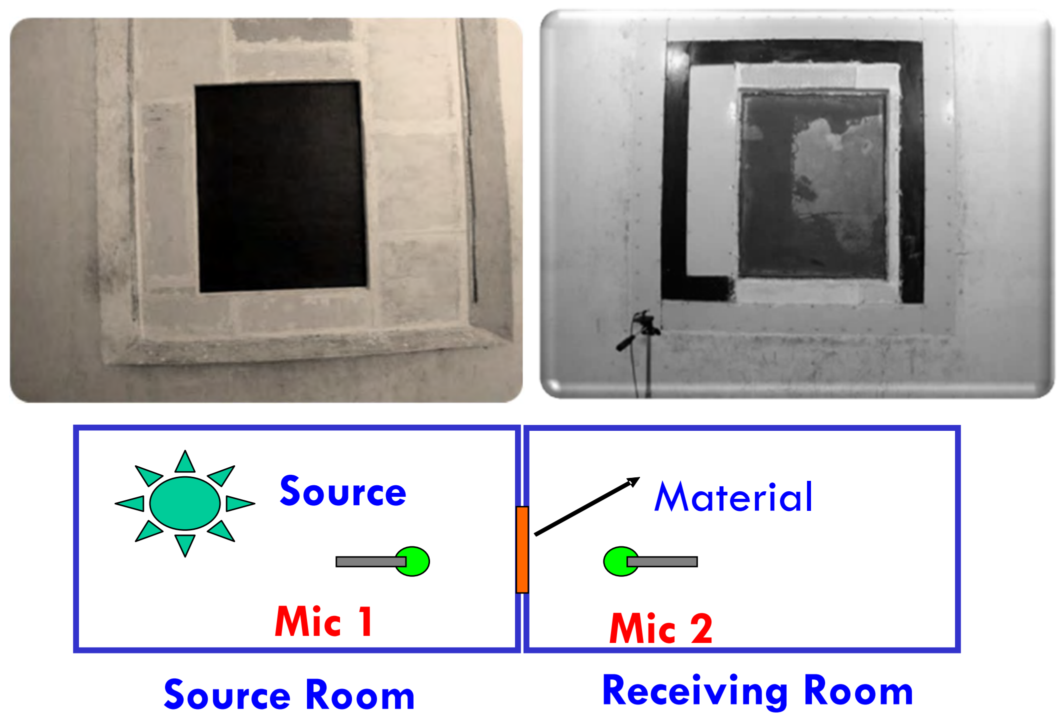
Sound Transmission Loss

- It is defined as the ratio of sound power incident on a partition to the sound power transmitted through the partition.

$$\tau = \frac{Sound\ Power\ Transmitted}{Sound\ Power\ Incident} \qquad STL = 10\log\left(\frac{1}{\tau}\right) \quad [dB]$$



Sound Transmission Loss Measurement in Four Microphone Tube



Random Incidence Sound Transmission Loss in a Reverberation Room

Measurement of Normal Incidence Sound Absorption and Transmission Loss-Three Microphone Impedance Tube

$$P\big|_{x=o} = \frac{H_{21}\sin kx_1 - \sin kx_2}{\sin k\left(x_1 - x_2\right)}$$

$$V\big|_{x=o} = \frac{jk}{\omega\rho_0}\frac{\cos kx_2 - H_{21}\cos kx_1}{\sin k\left(x_1 - x_2\right)}$$

$$P\big|_{x=d} = H_{31} \qquad V\big|_{x=d} = 0$$

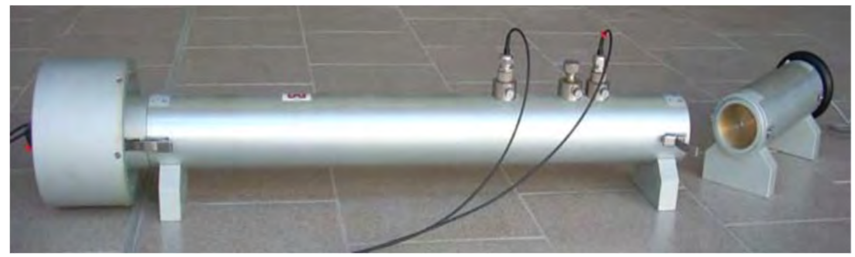
$P\big|_{x=o}$, $V\big|_{x=o}$ are the pressure and velocity at $x = 0$

$P\big|_{x=d}$, $V\big|_{x=d}$ are the pressure and velocity at $x = d$

H_{ij} is the transfer function between the i^{th} and j^{th} microphones

x : is the position of the microphones

ρ_0 : is the ambient density of the air, k : wave number



From reciprocity condition and symmetry condition

$$T_{11} = \frac{P\big|_{x=d}V\big|_{x=d} + P\big|_{x=0}V\big|_{x=0}}{P\big|_{x=d}V\big|_{x=d} + P\big|_{x=0}V\big|_{x=d}}$$

$$T_{12} = \frac{P\big|^2_{x=0} - P\big|^2_{x=d}}{P\big|_{x=d}V\big|_{x=d} + P\big|_{x=0}V\big|_{x=d}}$$

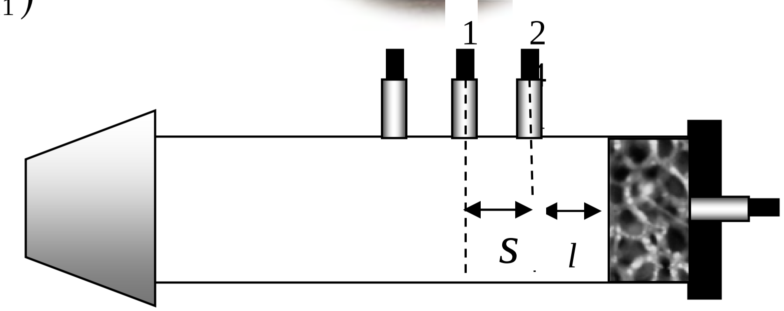
$$T_{21} = \frac{V\big|^2_{x=0} - V\big|^2_{x=d}}{P\big|_{x=d}V\big|_{x=d} + P\big|_{x=0}V\big|_{x=d}}$$

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} = \begin{bmatrix} \cos(\gamma d) & \frac{j}{Z_c}\sin(\gamma d) \\ jZ_c\sin(\gamma d) & \cos(\gamma d) \end{bmatrix}$$

$$Z_c = \sqrt{\frac{T_{12}}{T_{21}}} \qquad k_c = \frac{1}{d}\cos\left(T_{11}\right)$$

$$Z_s = Z_c.\cos\left(k_c\, d\right) \quad [\text{Ns/m}^3]$$

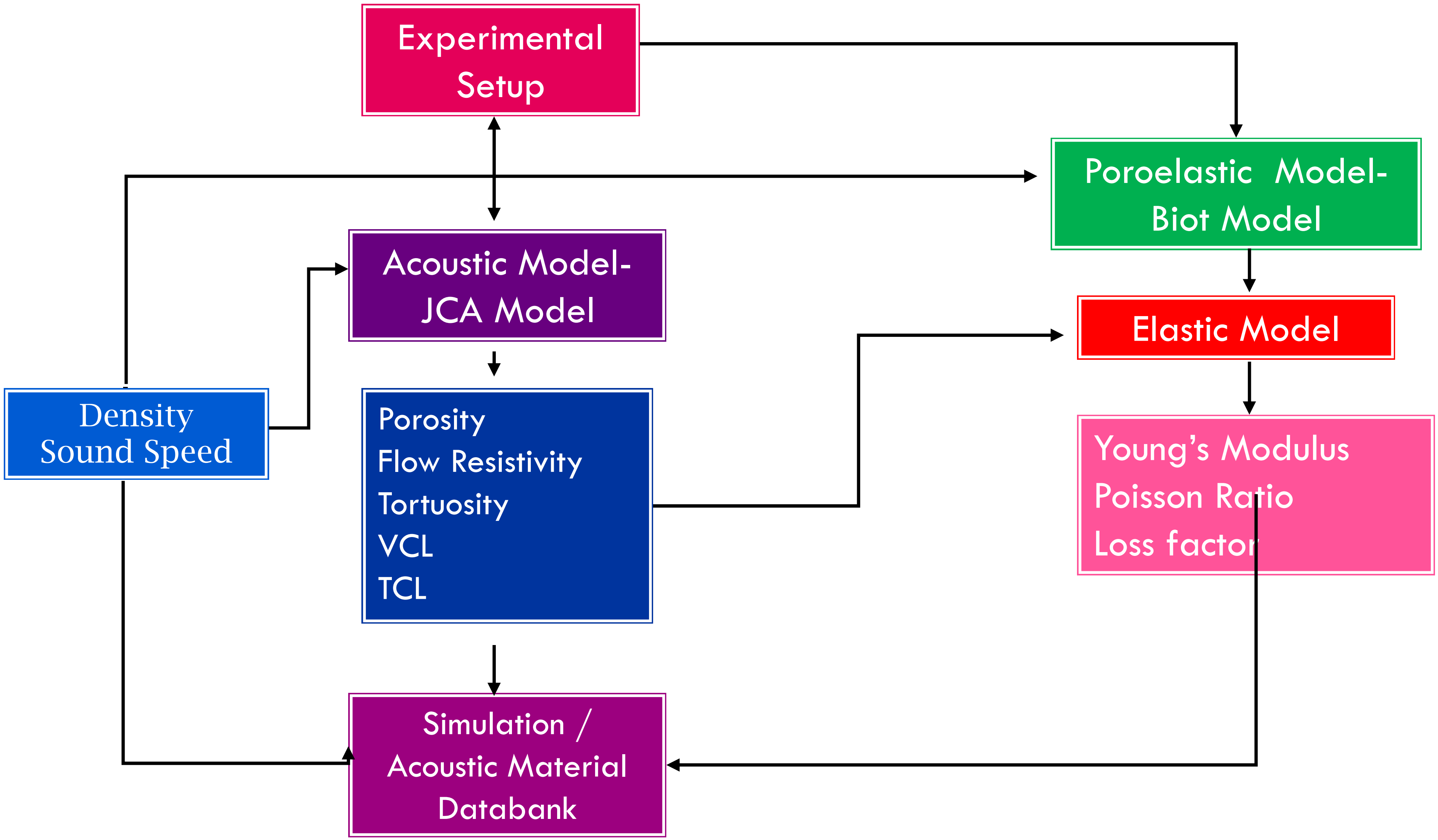
Impedance Tube Test



$$\alpha = \frac{4.\mathrm{Re}(Z_s).\rho_0 c_0}{\left|Z_s\right|^2 + 2\rho_0 c_0.\mathrm{Re}(Z_s) + \left(\rho_0 c_0\right)^2}$$

$$\tau = \frac{2}{\sin kd\left(2\coth\left(kd\right) + \frac{Z_c}{\phi Z_0} + \frac{\phi Z_0}{Z_c}\right)}$$

Inverse Chracterization Techniques



Inverse Techniques

- **Parameters to be determined**

  The physical parameters of poroelastic materials determined are ϕ, σ, α_∞, Λ and Λ'.

- **Principle of Measurement**

  Inverse characterization from the low frequency measurement of the surface impedance and complex acoustical properties inside the impedance tube.

- **Precision**

  Errors are generally below 5% for all physical parameters.

- **Methods**

  Analytical Inverse

  Optimization Method

Analytical Inverse: Tortuosity, VCL & TCL

- Tortuosity from real part of bulk density

$$\alpha_\infty = \frac{\varphi}{\rho_0}\left(\mathrm{Re}\left(\rho(\omega)\right) - \sqrt{\mathrm{Im}\left(\rho(\omega)\right)^2 - \frac{\sigma^2}{\omega^2}}\right)$$

- Viscous Chracteristic Length from imagenary part of bulk density

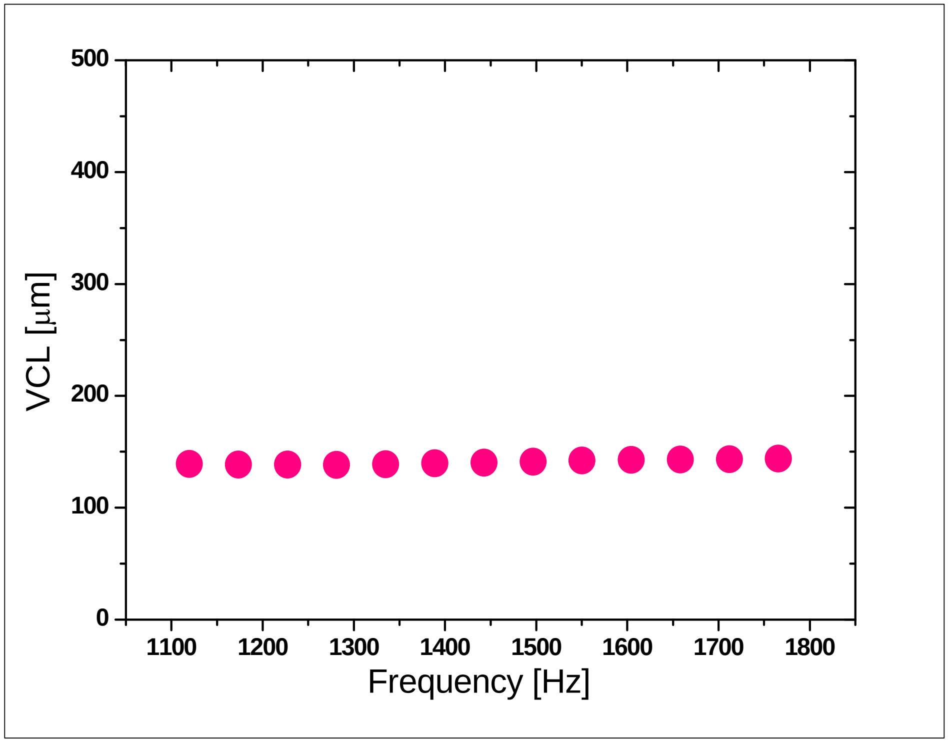
$$\Lambda = \frac{\alpha_\infty}{\varphi}\left(\frac{2\eta\rho_0}{\omega\,\mathrm{Im}\left(\rho(\omega)\right)\left(\alpha_\infty\rho_0/\varphi - \mathrm{Re}\left(\rho(\omega)\right)\right)}\right)$$

- Thermal Chracteristic Length from imagenary part of bulk modulus (Lafarge's Model)

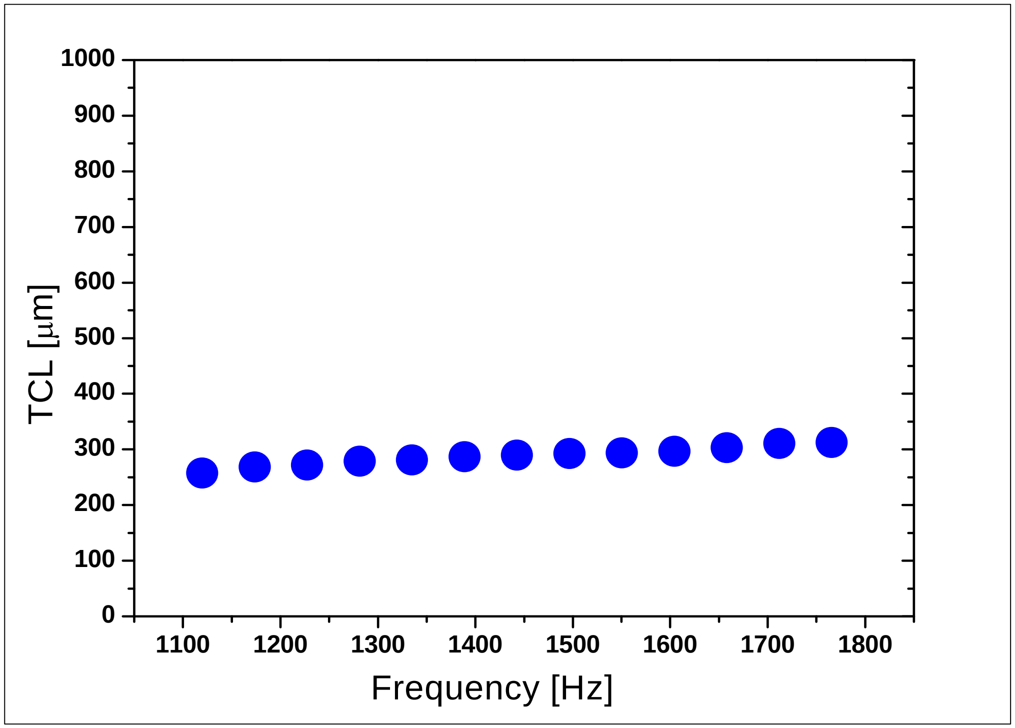
$$\Lambda' = 2\sqrt{\frac{\kappa}{\rho_0 C_p \omega}}\left(-\mathrm{Im}\left(\left(\frac{\gamma P_0 - \varphi K(\omega)}{\gamma P_0 - \gamma\varphi K(\omega)}\right)^2\right)\right)^{-1}$$

Characteristics Lengths-Computed

- VCL and TCL are computed at mid frequency range 1100-1800 Hz



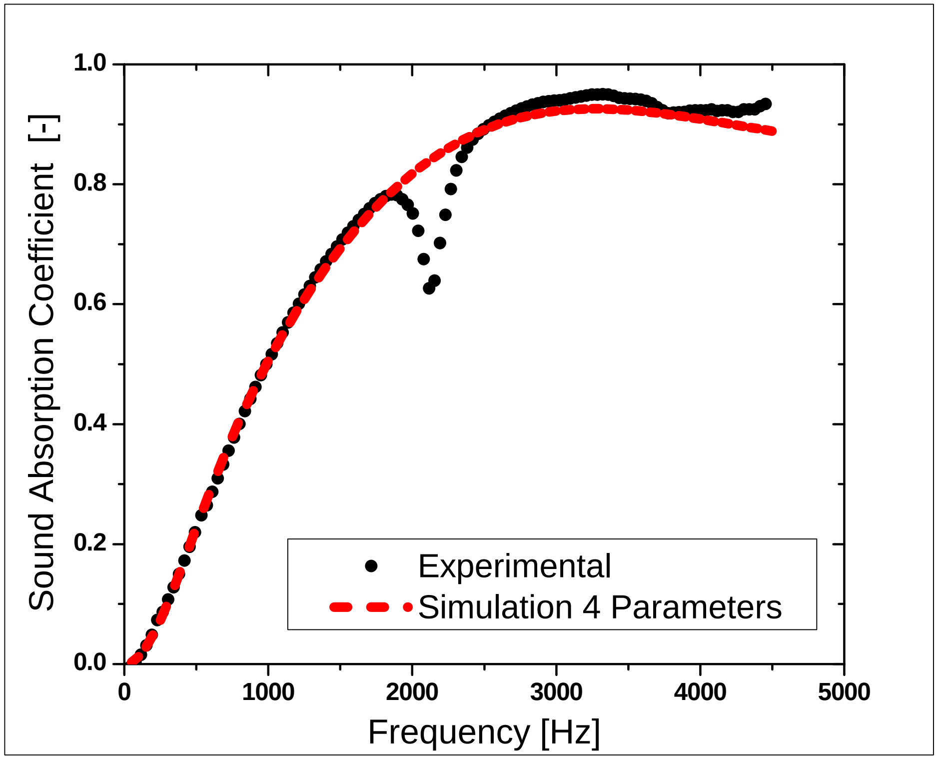
Computed VCL



Computed TCL

Analytical Inverse-Results

- Melamine Foam 20 mm



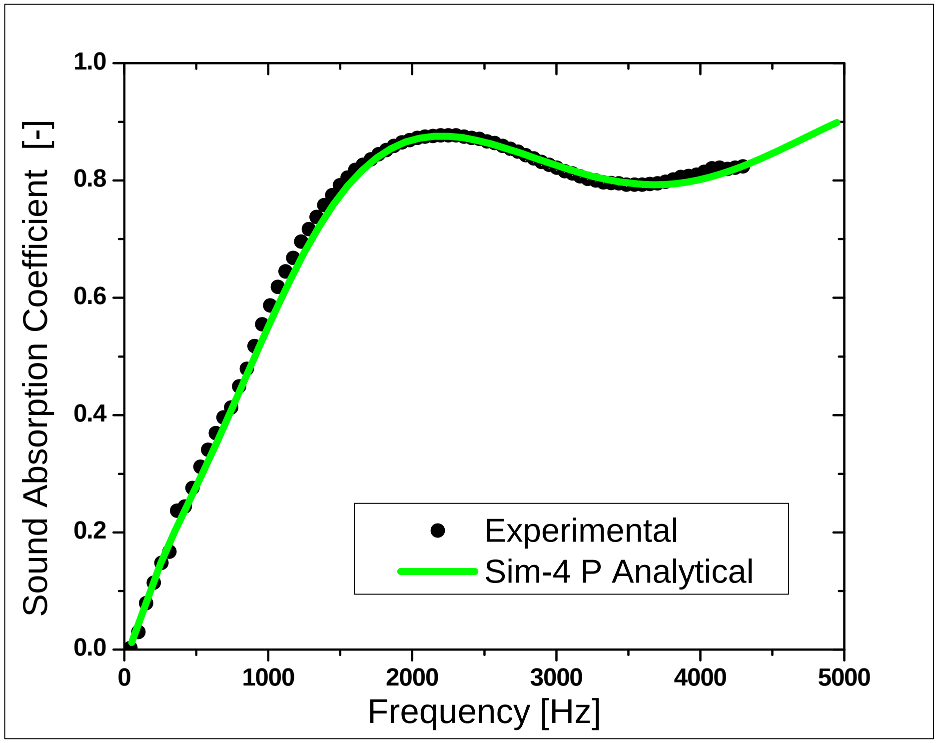
Comparison of experimental and simulated SAC using inverted Parameters

	Exp.	Inverse
σ	10518	10634
ϕ	0.99	0.98
α_∞	1.01	1
Λ	107	99
Λ'	137	180

Comparison of experimental and inverted Parameters

Analytical Inverse-Results

- Polyurethane Foam 25 mm

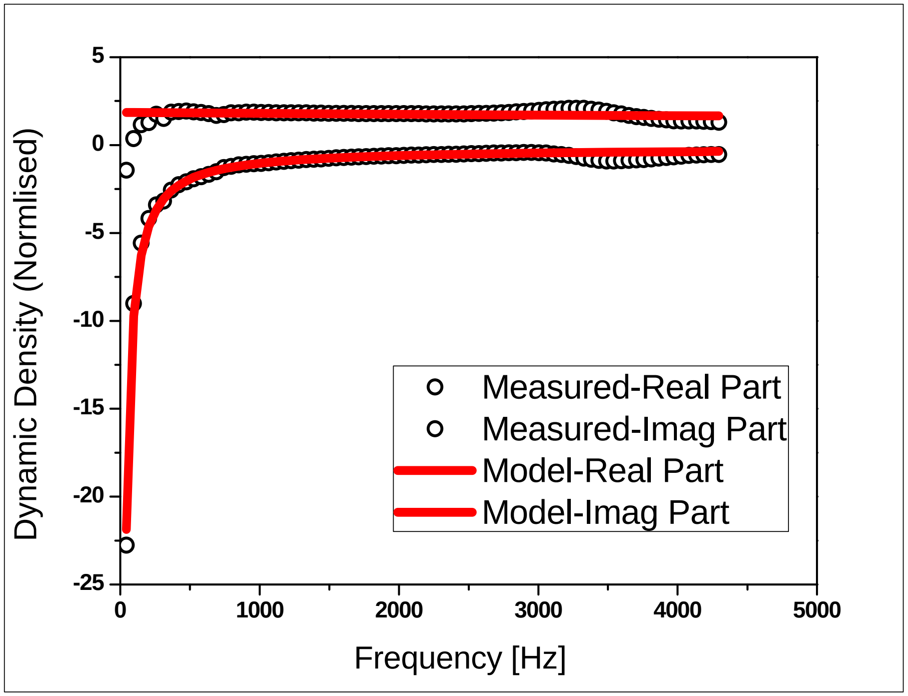


Comparison of experimental and simulated SAC using inverted Parameters

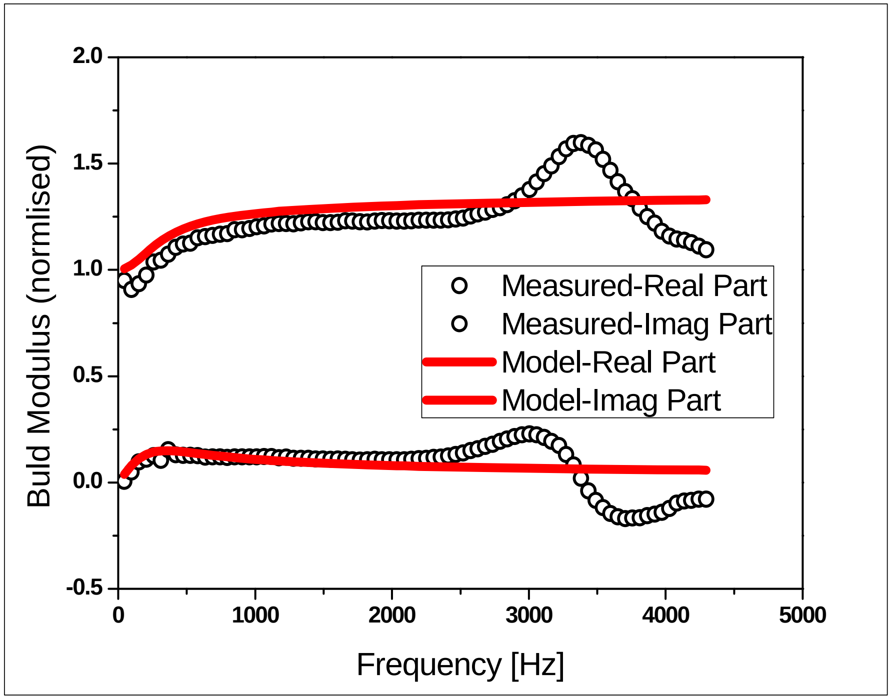
	Exp.	Inverse
σ	5359	6036
ϕ	0.98	0.98
α_∞	1.1	1.11
Λ	48	125
Λ'	240	295

Comparison of experimental and inverted Parameters

Analytical Inverse-Results



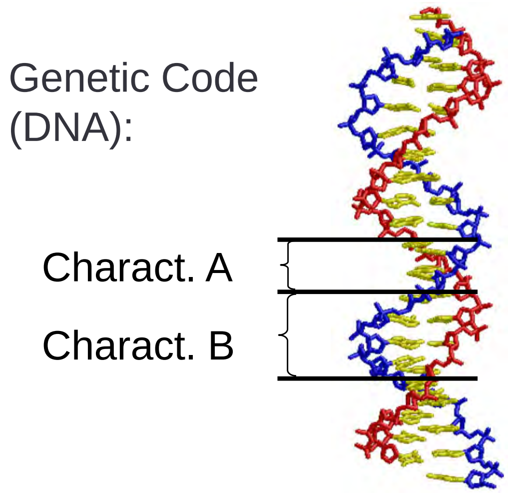
Comparison of measured and predicted dynamic density of for PU-foam



Comparison of measured and predicted bulk modulus of for PU-foam

Optimization Inverse Method-Genetic Algorithm

Natural Selection



- The genetic algorithm is a method for solving both constrained and unconstrained optimization problems that is based on "natural" selection. Over successive generations, creating "children" from the best "parents", the population "evolves" toward an optimal solution.
- In this analysis the surface impedance of the material put on a rigid wall has been used as cost function:

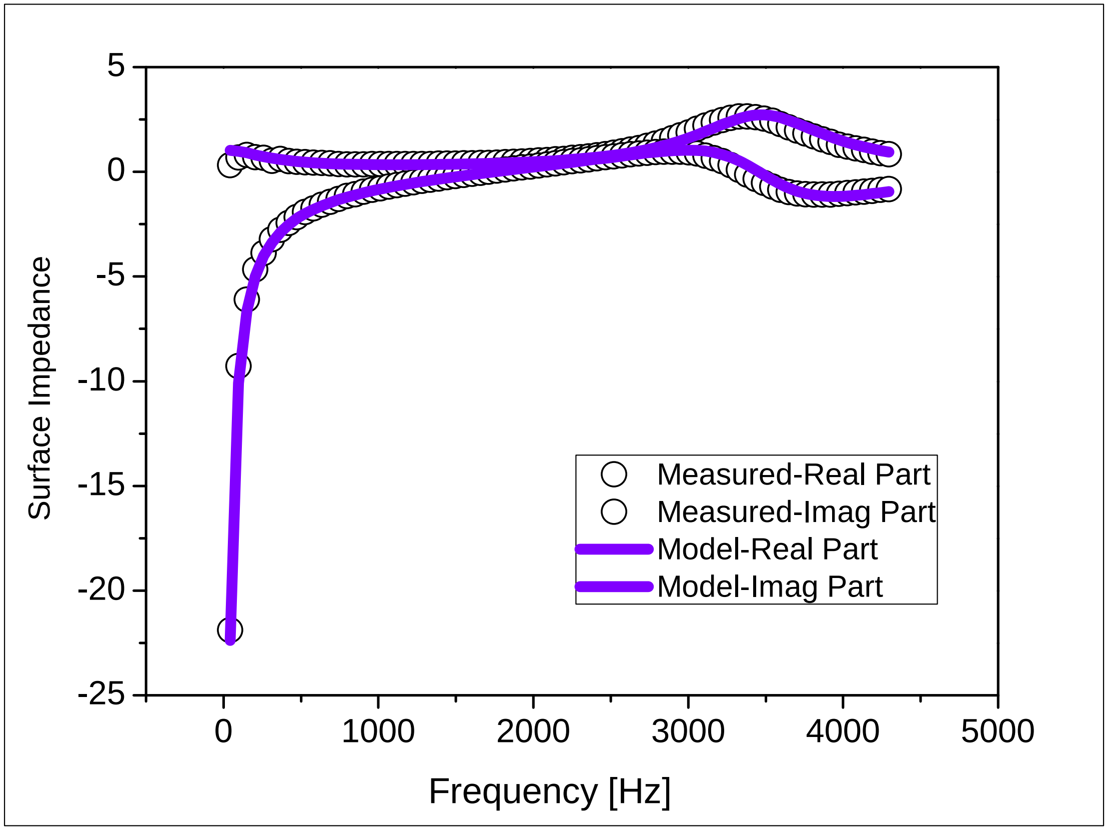
$$CF\{|Zs|\} = \sum \left| Z_S^{meas} - Z_S^{model} \right|$$

Z_S^{meas} Measured Surface Impedance

Z_S^{model} Predicted Surface Impedance-Allard Model

Inverse Technique (Genetic Algorithm)

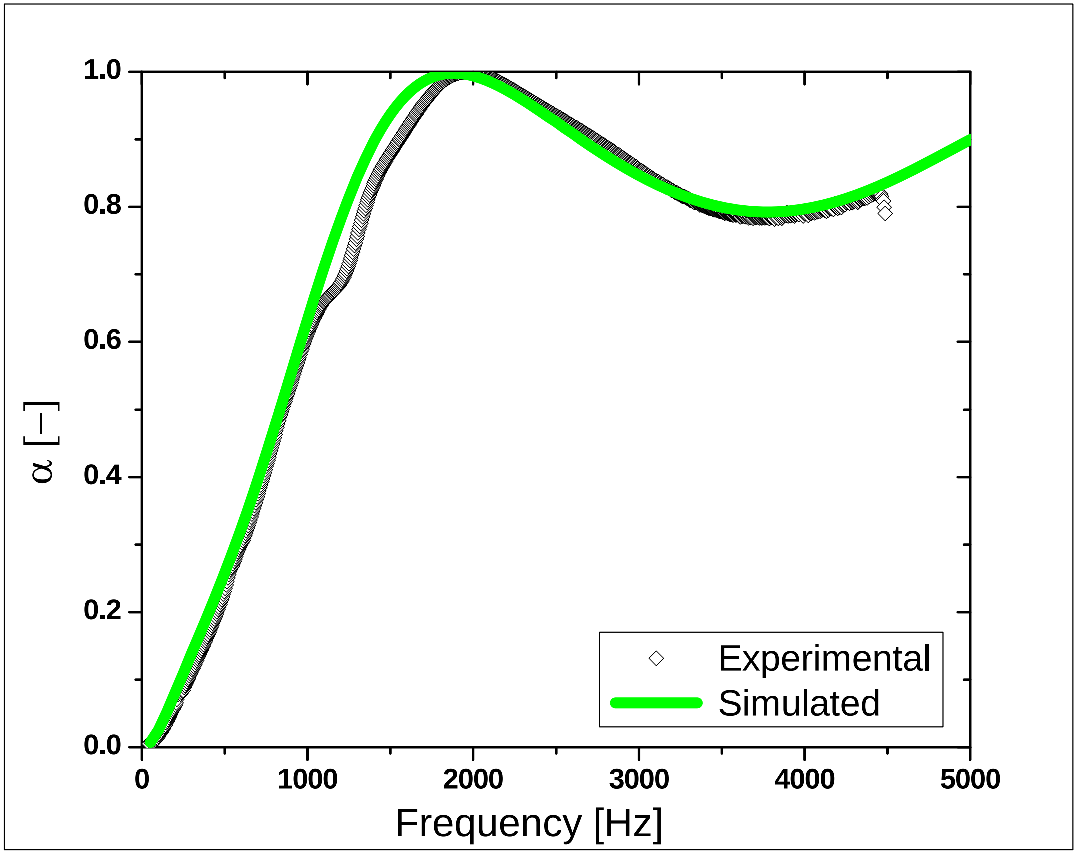
- Polyurethane Foam



Comparison of surface Impedance
Measured and Simulated-Genetic Algorithm

Inverse Technique (Genetic Algorithm)

- Polyurethane Foam-25 mm

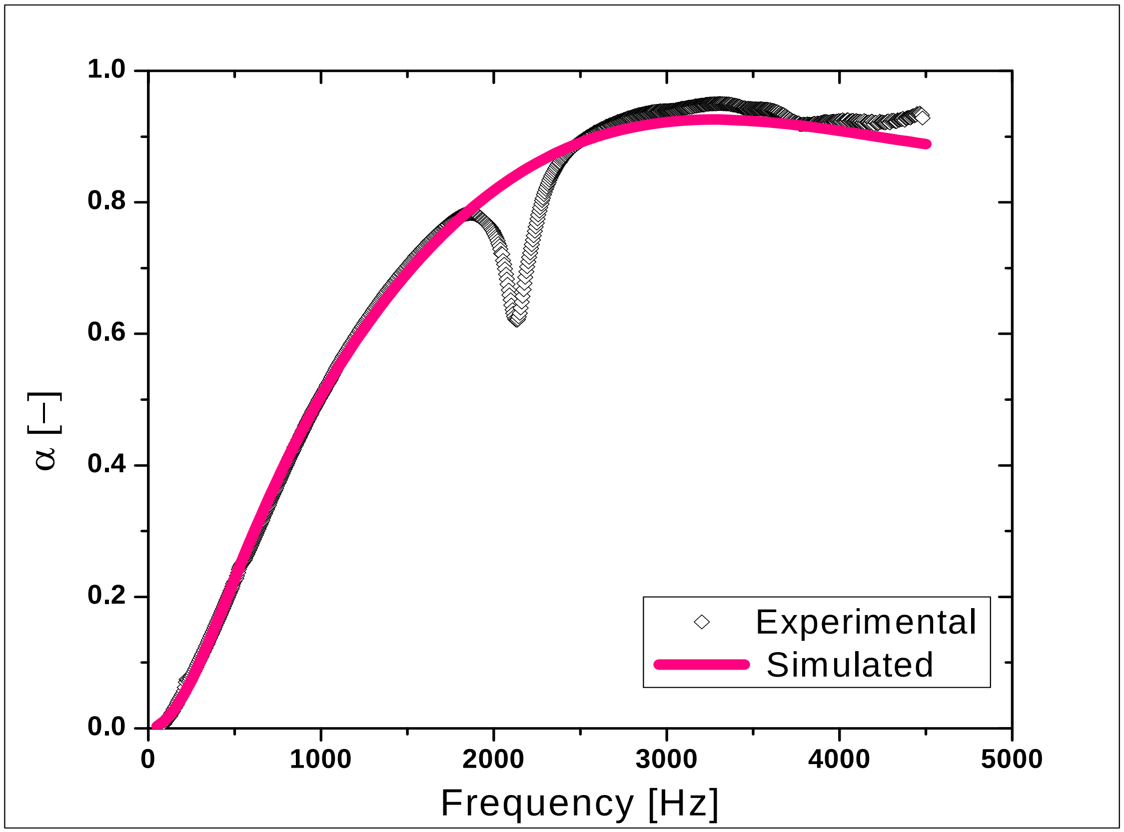


Comparison of Sound absorption coefficient Measured and Simulated

	Exp.	Inverse
σ	24119	23327
ϕ	0.98	0.98
α_∞	1.76	1.72
Λ	48	43
Λ'	240	258

Inverse Technique (Genetic Algorithm)

- Melamine Foam-29 mm



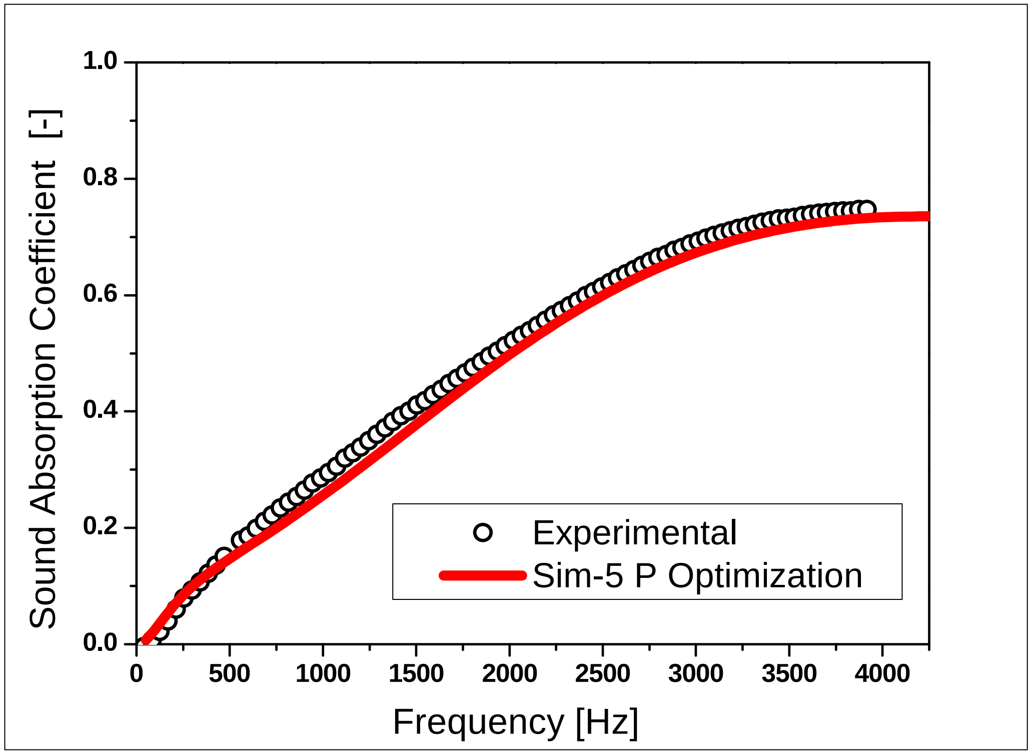
Comparison of Sound absorption coefficient Measured and Simulated

	Exp.	Inverse
σ	10518	10872
ϕ	0.99	0.99
α_∞	1.01	1
Λ	107	99
Λ'	137	142

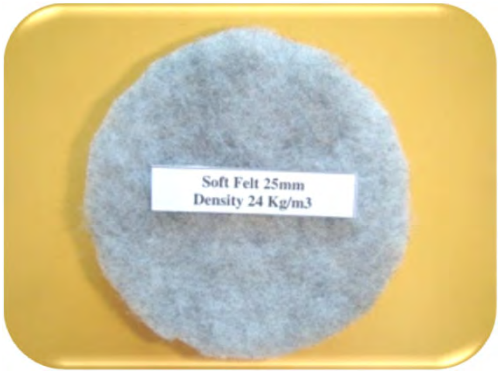
Comparison of experimental and inverted Parameters

Inverse Technique (Genetic Algorithm)

- PET Felt 25mm



Comparison of Sound absorption coefficient Measured and Simulated



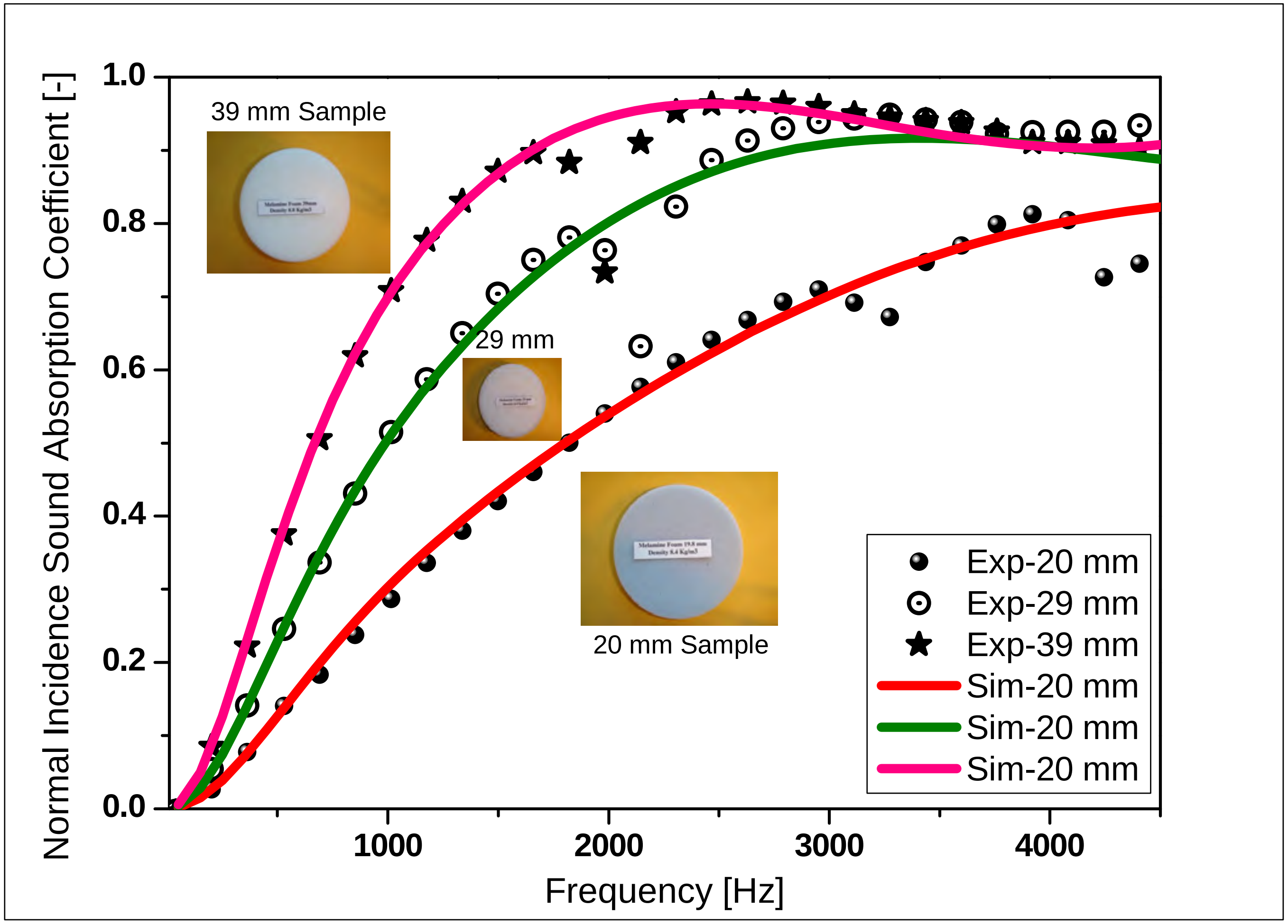
	Exp.	Inverse
σ	6114	5931
ϕ	0.99	0.99
α_∞	1.03	1.02
Λ	140	165
Λ'	230	294

Comparison of experimental and inverted Parameters

Intrinsic Parameters-Melamine Foam 20 mm-10 Kg/m^3

Intrinsic Parameters

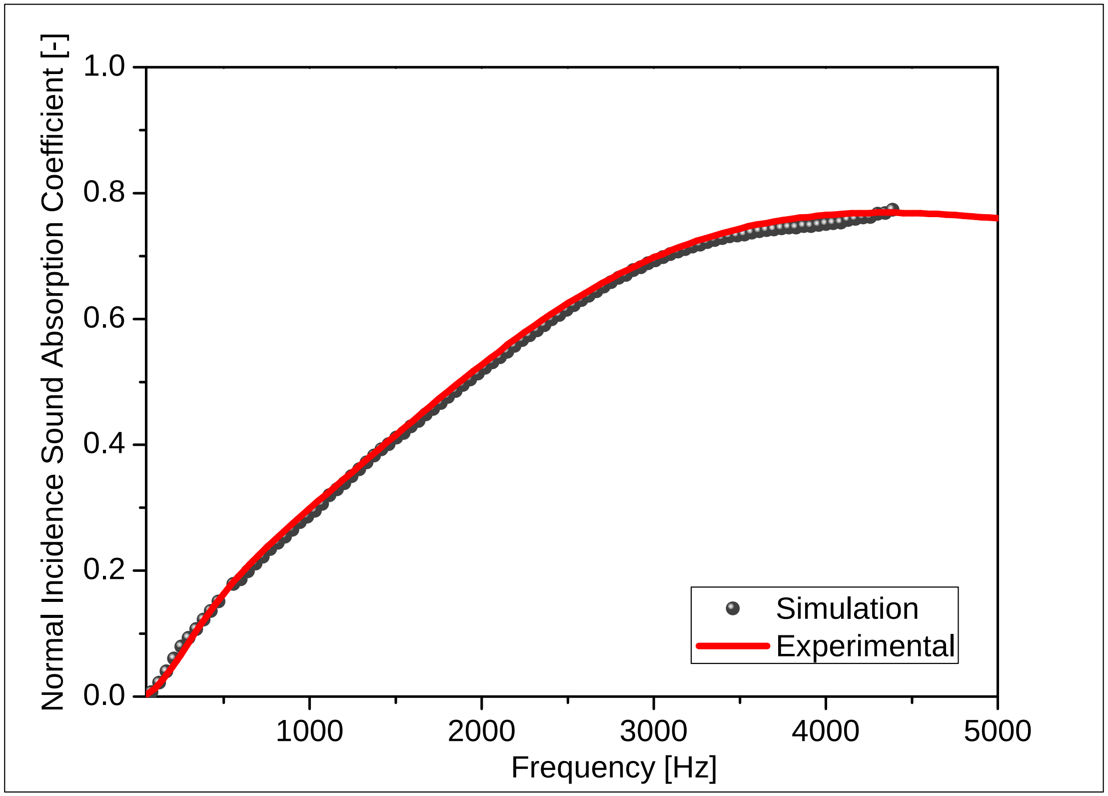
	Inverse
σ	10872
Φ	0.99
α_∞	1
Λ	99
Λ'	142



Simulation and Validation- Sound Absorption

PET Felt – 25 mm-24 Kg/m^3

Symbol	Value
ϕ	0.99
σ	6634
α_∞	1.06
Λ	147
Λ'	203
E	10140
ν	0
η	0.12

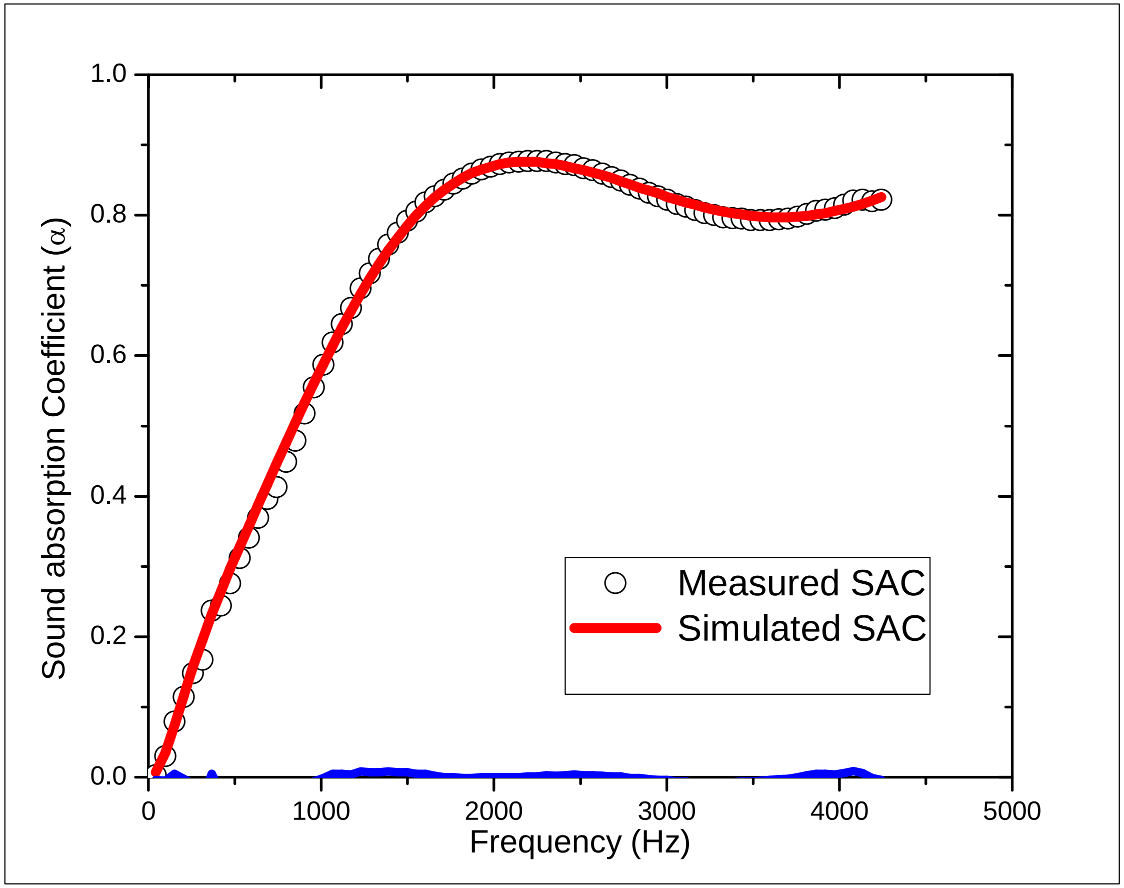


Comparison of Sound absorption coefficient Measured and Simulated

Simulation and Validation- Sound Absorption

Polyurethane Foam-40mm-40Kg/m^3

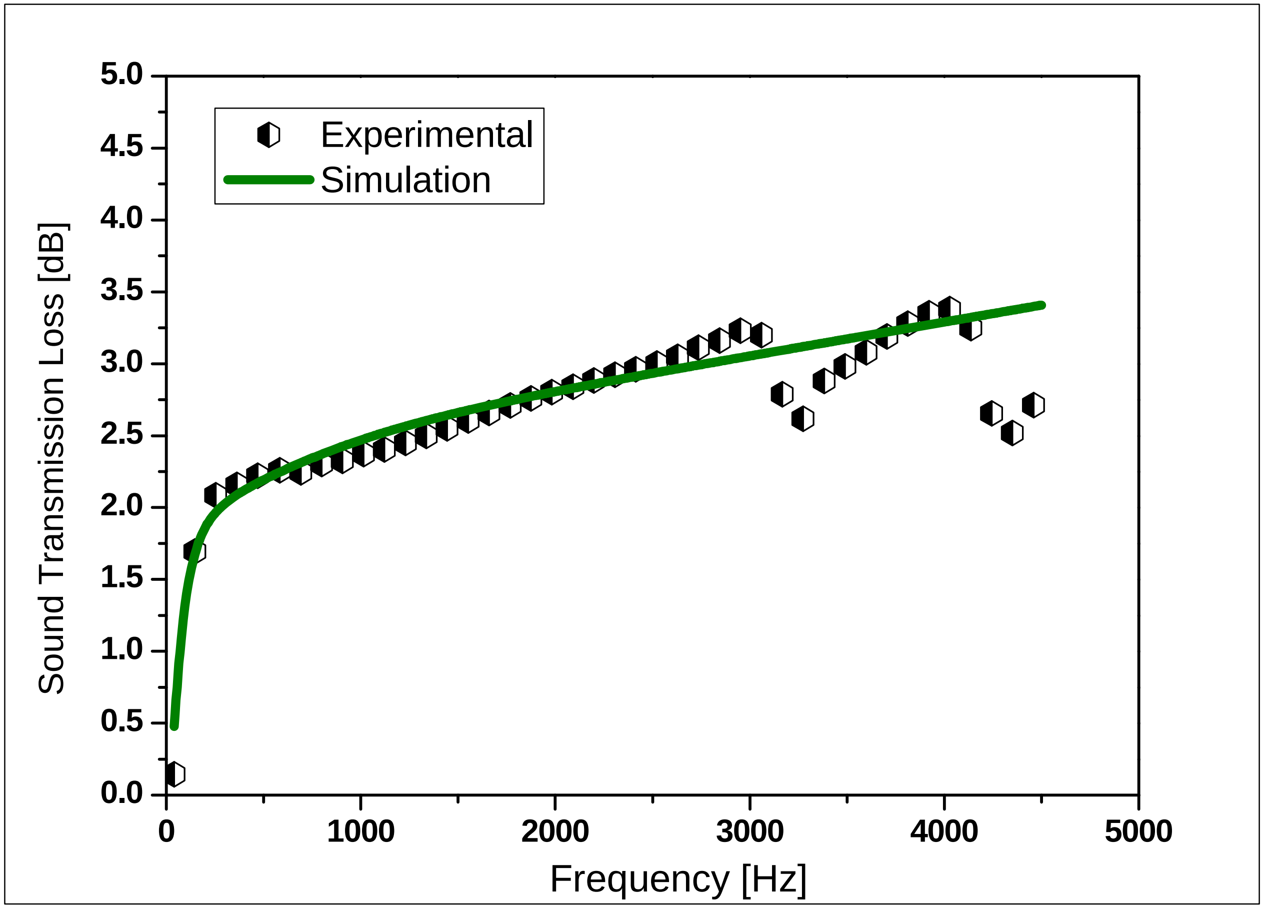
Symbol	Value
ϕ	0.98
σ	5359
α_∞	1.08
Λ	119
Λ'	235
E	119930
ν	0.33
η	0.09



Comparison of Sound absorption coefficient Measured and Simulated

Simulation and Validation–Sound Transmission

Symbol	Value
ϕ	0.99
σ	10518
α_∞	1.01
Λ	107
Λ'	137
E	80000
ν	0.28
η	0.07



Comparison of Sound Transmission Loss Measurement and Simulation

Random Incidence Sound Absorption Measurement

- Reverberation Room- [ISO 354/ ASTM 423]

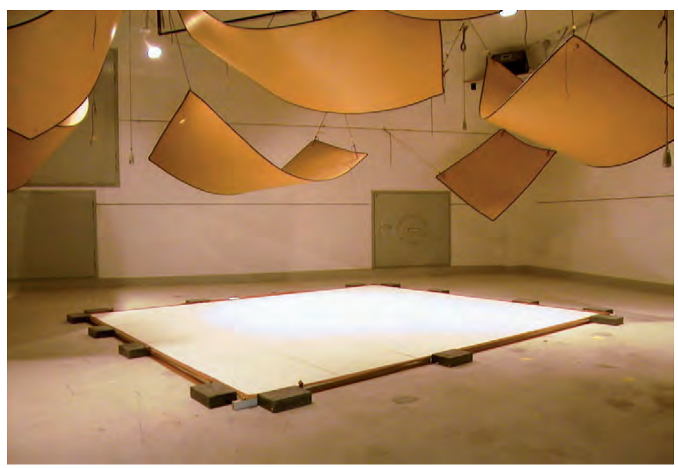
  Sound absorption is measured using Sabine's Formula

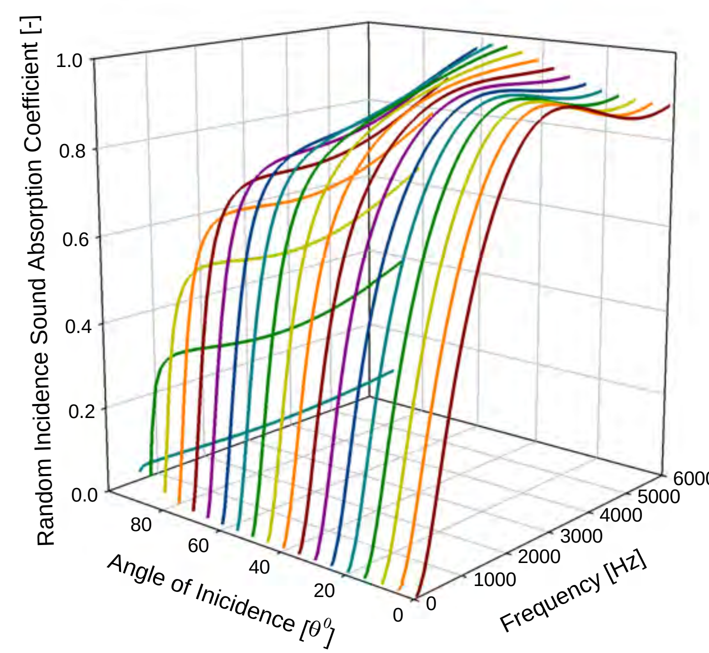
$$A_1 = \frac{55.3V}{cT_1} - 4Vm_1$$ Without Material

$$A_2 = \frac{55.3V}{cT_2} - 4Vm_2$$ With Material

$$A_T = \frac{55.3V}{c}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

$$\alpha_{random} = \frac{A_T}{S}$$

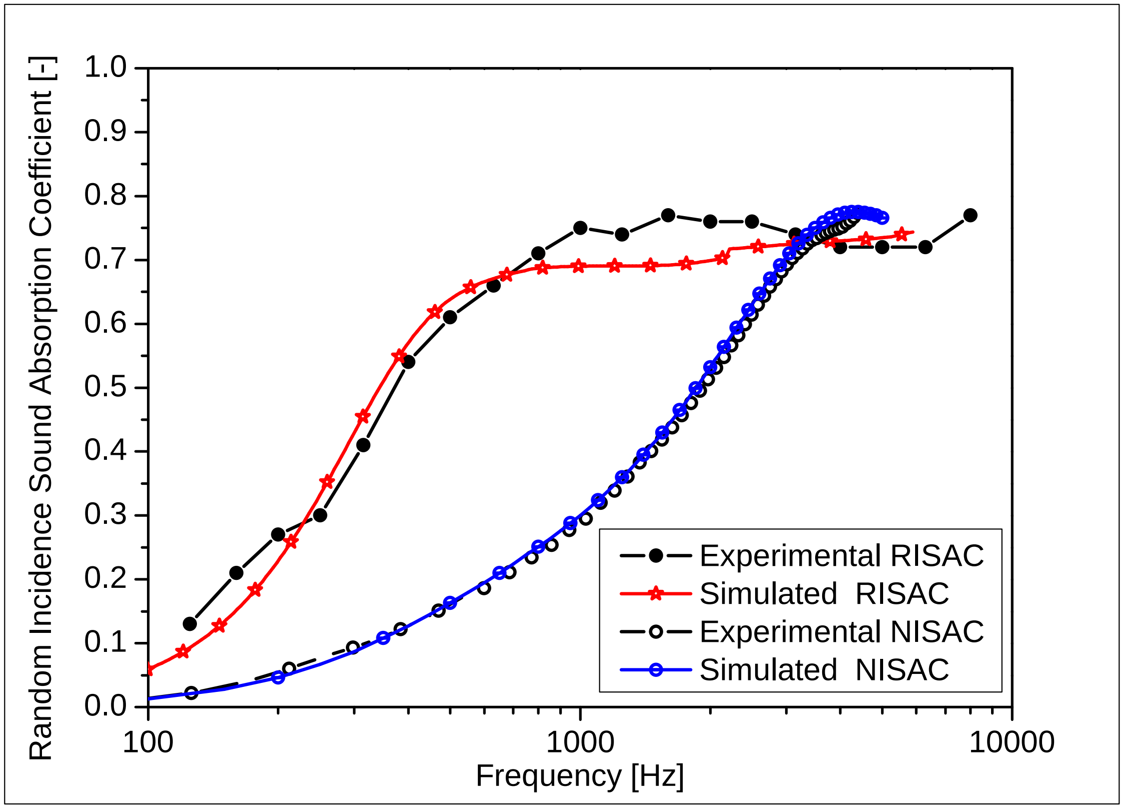




Simulation and Validation-Sound Absorption

PET Felt-25mm-24Kg/m^3

Symbol	Value
ϕ	0.99
σ	6114
α_∞	1.03
Λ	140
Λ'	230
E	8000
ν	0.02
η	0.017



Comparison of Random Sound absorption coefficient Measurement and Simulation

Random Incidence Sound Transmission Loss - Reverberation Suite

- Two adjacent reverberation rooms are arranged with an opening between them in which the test partition is installed as per ASTM E90.
- Sound Transmission loss is related to Noise reduction as

$$TL = NR + 10\log_{10}\left(\frac{S}{A}\right)$$

S-Area of the sample

A- Room constant of the receiving room

- Noise Reduction is simply the difference between sound pressure levels on opposite sides of a wall

SPL_1 – Sound Pressure Level in the Room 1

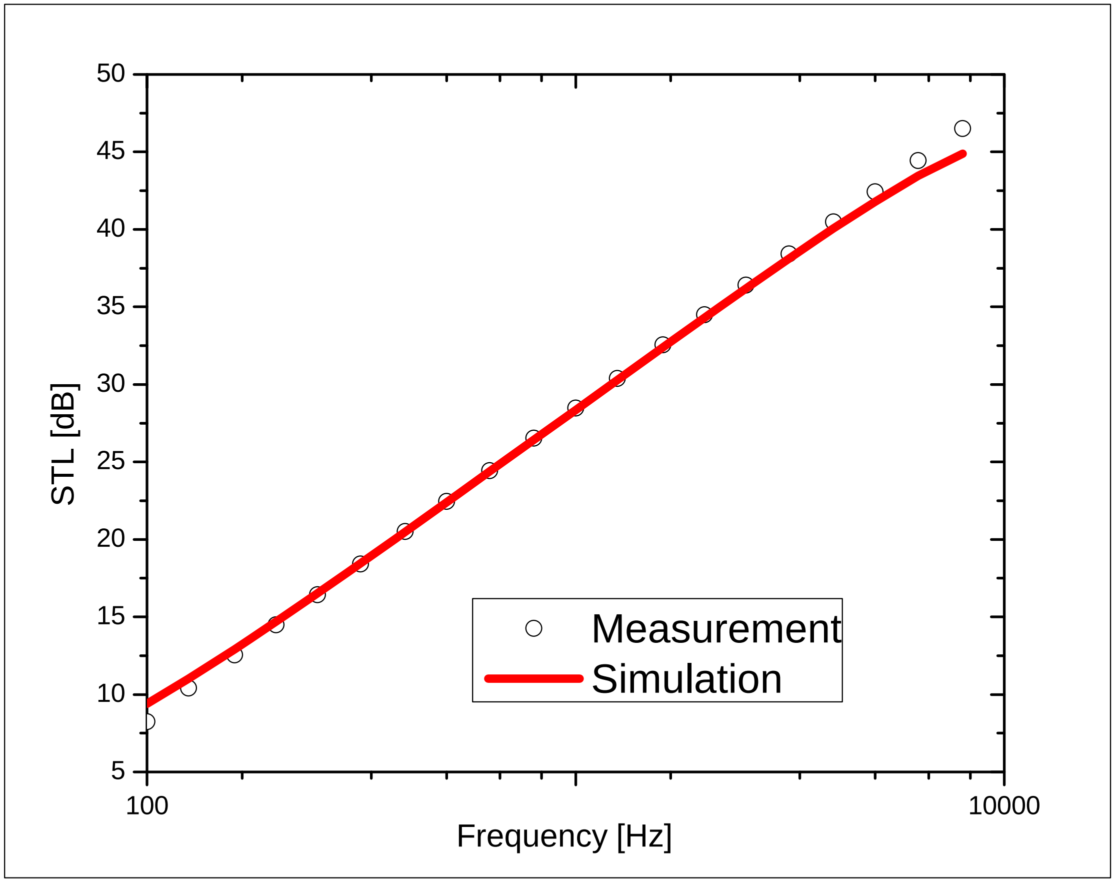
SPL_2 – Sound Pressure Level in the Room 2

$$NR = SPL_1 - SPL_2$$

Random Sound Transmission Loss of Steel Plate

Steel Plate

Symbol	Value
ρ	7800 [Kg/m^3]
E	2E11 [N/m^2]
ν	0.28 [-]
η	0.001 [-]

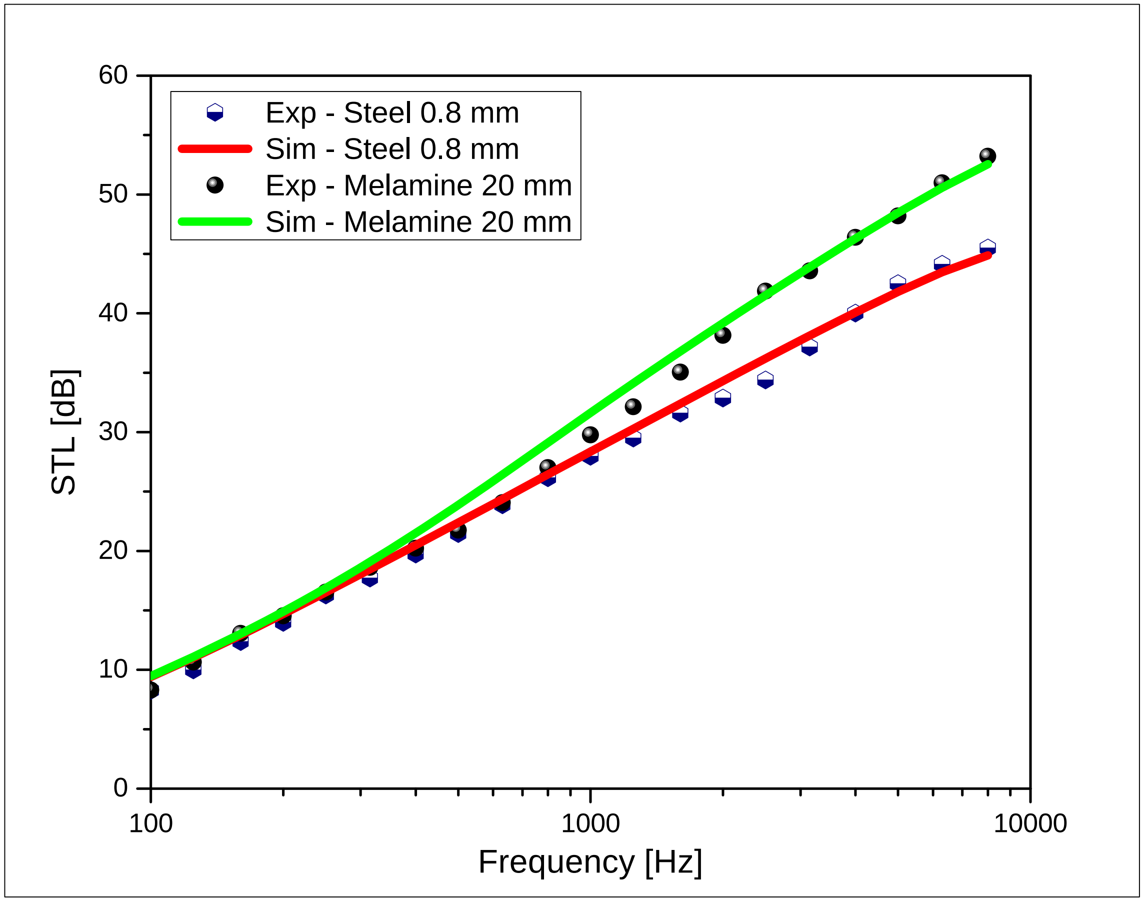


Random Sound Transmission Loss of Steel Plate
(0.8mm measured with Two chamber Method)

Steel Plate 0.8 mm + Foam 20 mm- Simulation

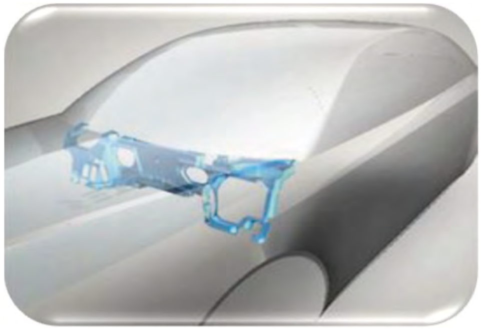
- Test was carried out in a Reverberation room with Anechoic chamber as a receiver room

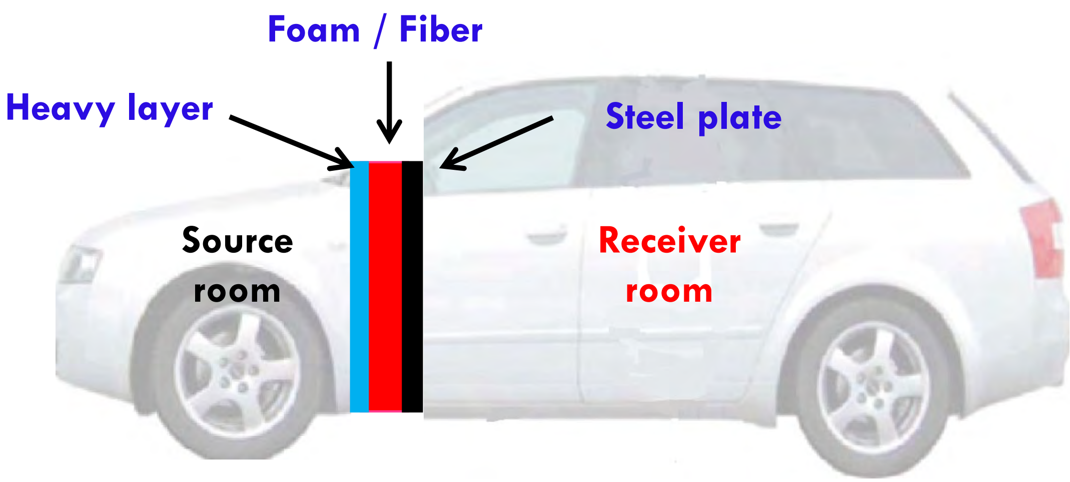
Symbol	Value
ϕ	0.99
σ	10518
α_∞	1.01
Λ	107
Λ'	137
E	80000
ν	0.28
η	0.07



Vehicle Dash Insulator

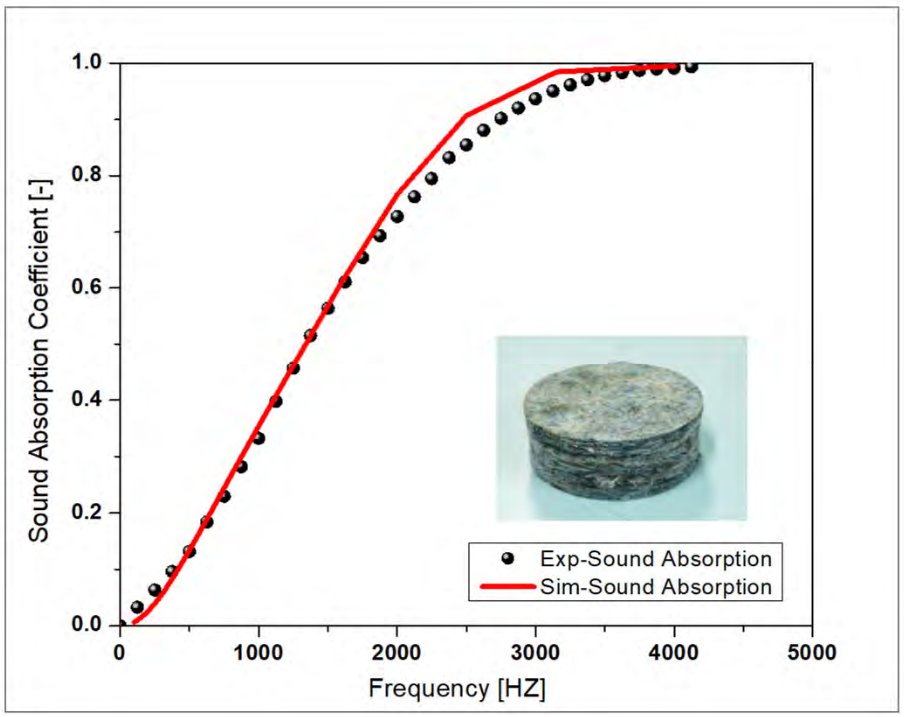
- It seperates Engine compartment from Passenger cabin
- A typical dash insultor consists of Steel plate + Porous Decoupler + Heavy Layer
- Resonating Frequency Range in between 100 Hz to 500 Hz which is similar to Engine firing frequency.



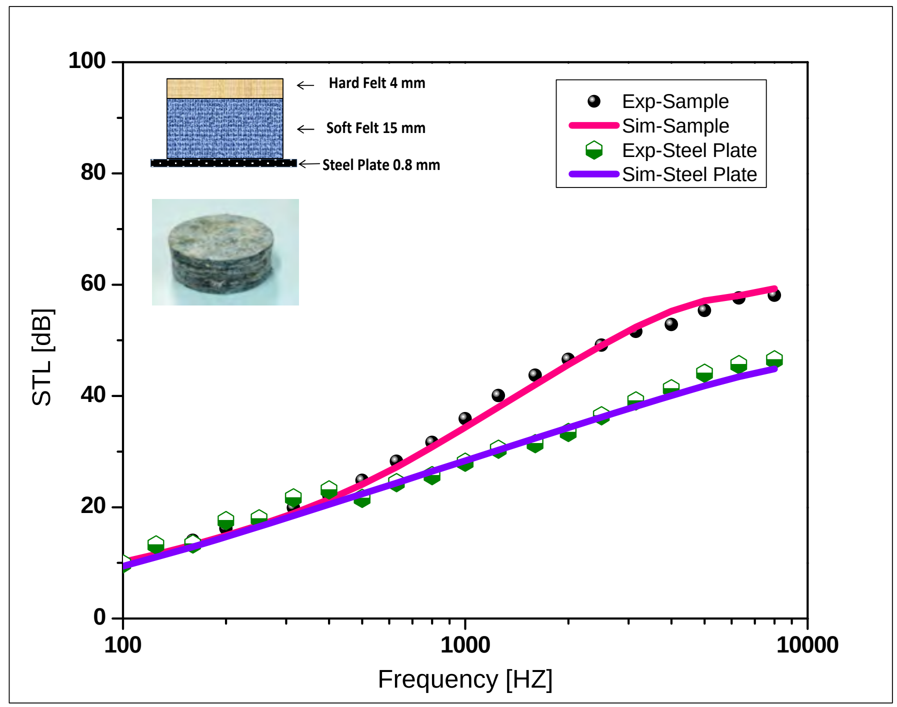


Vehicle Dash -Simulation and Validation

	Thickness	Density	ϕ	σ	α_∞	Λ	Λ'
	[mm]	[Kg/m^3]	[-]	[Ns/m^4]	[-]	[μm]	[μm]
Hard Felt	4 mm	250	0.91	150000	2.01	4.2	150
Soft Felt	15 mm	48	0.97	15500	1.5	140	150



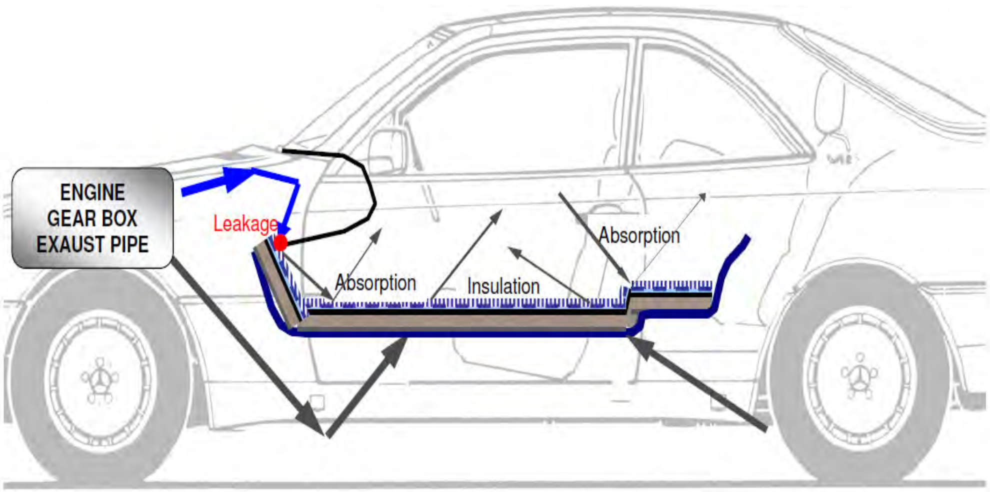
Comparison of Experimental Sound Absorption with Simulation for Dash 2



Comparison of Experimental Sound Transmission Loss with Simulation for Dash 2

Vehicle Floor Carpet

- It is the second larget part covering maximum area (11%) after headliners (21%)
- This is used to reduce Road as well as Engine noise inside cabin
- It consists of multiple layers of sound packages like foams, fibers, felts, EVA etc.



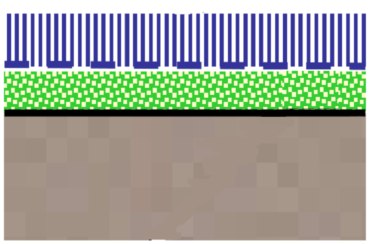
Material Characterization - Physical & Intrinsic Parameters

Physical Parameters

Sr. No.	Layers	Thickness	Density	Flow Resistivity	Porosity
		[mm]	[Kg/m^3]	[Ns/m^4]	[-]
1	PET with PVC	2mm	600	-	-
2	Soft Felt	15 mm	64	30000	0.90

Intrinsic Parameters

	σ	ϕ	α_∞	Λ	Λ'
Soft Felt	30000	0.90	1.2	215	215

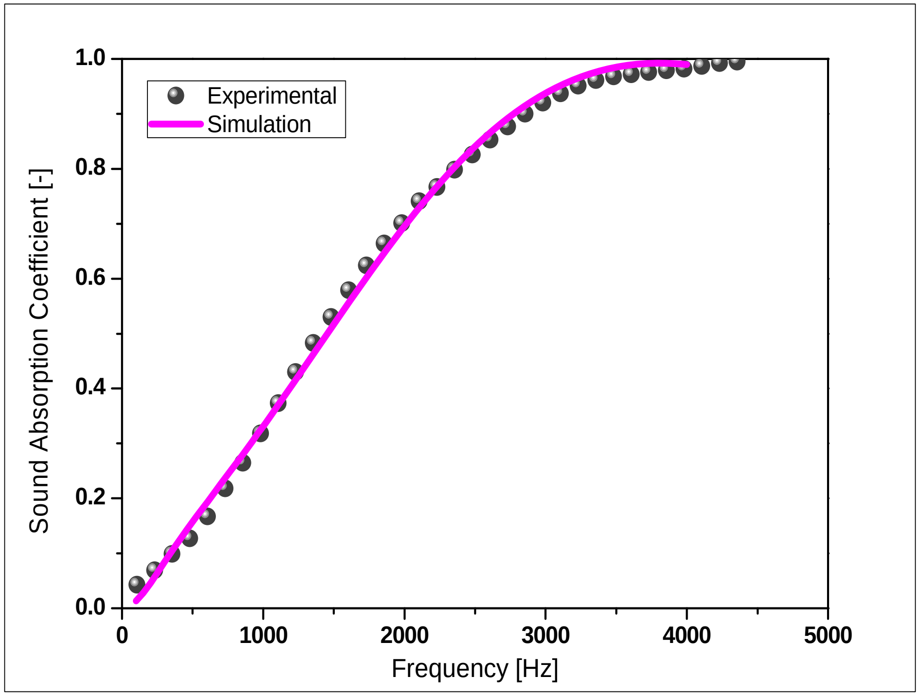



Soft Felt

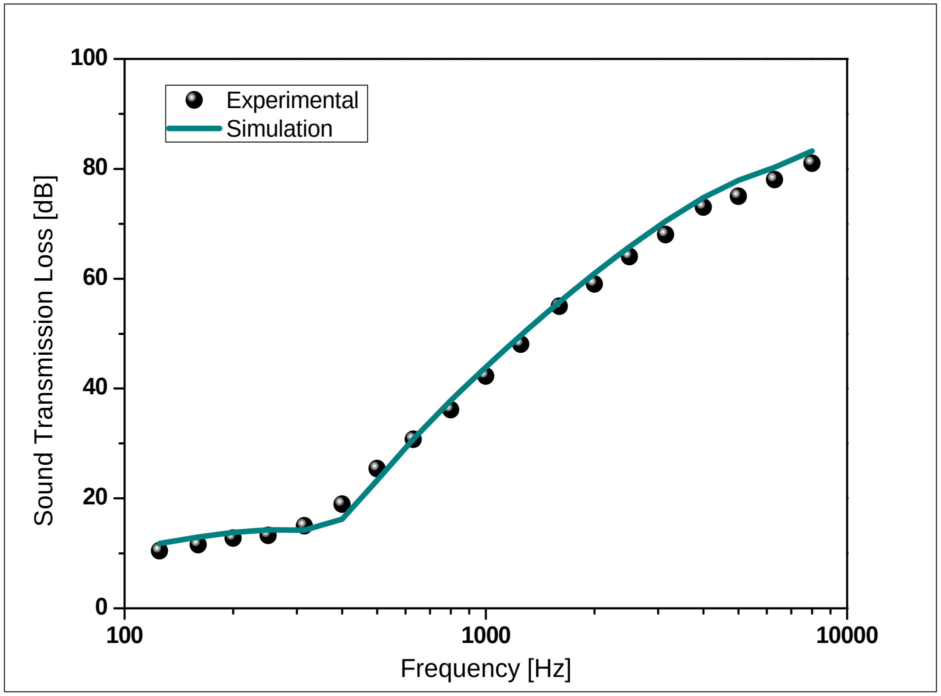

PET with PVC Layer


Carpet Sample 1

Simulation and Validation –Sound Absorption and Transmission Loss



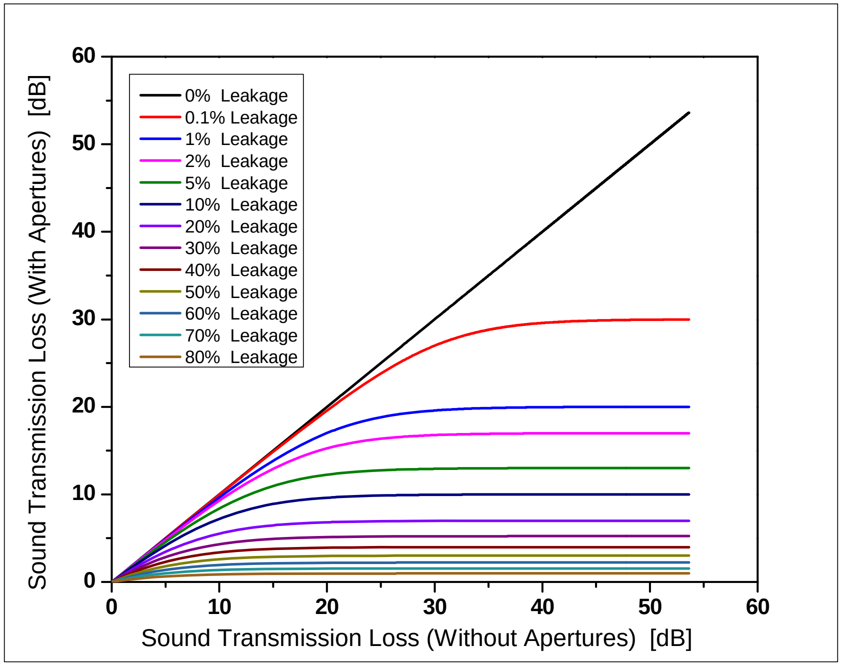
Vehicle Floor Carpet is tested inside an Impedance Tube

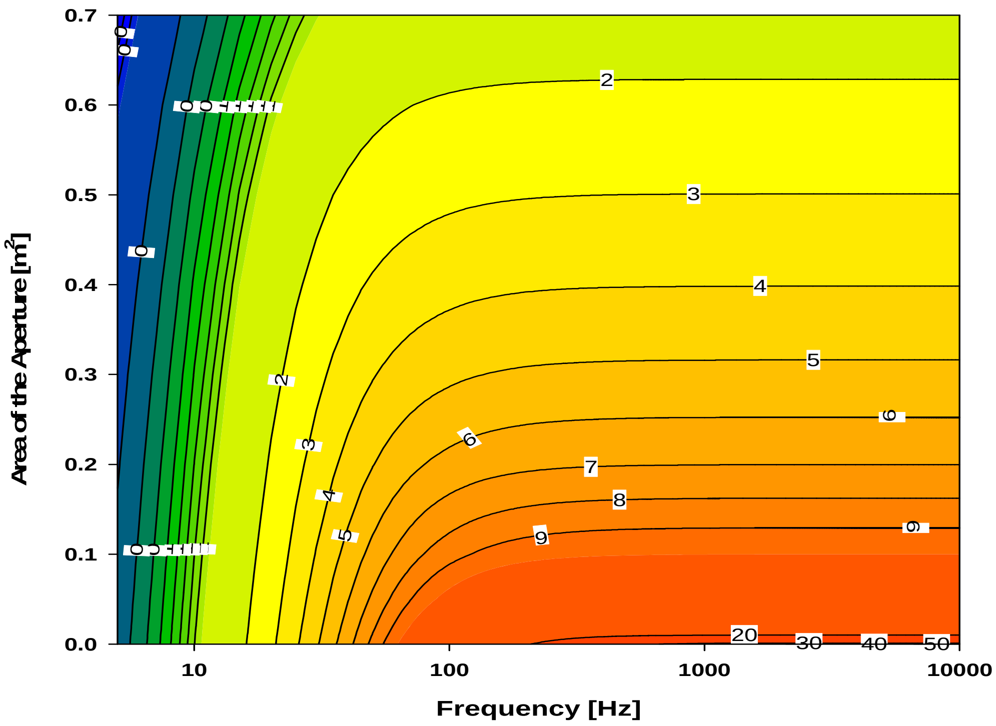


Vehicle Floor Carpet is tested with Steel Plate of 0.8 mm Thickness

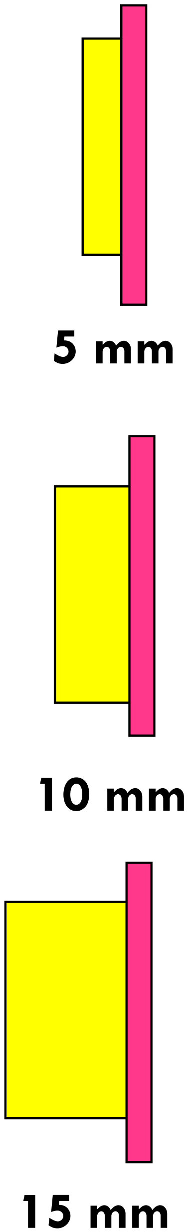
Effect of Apertures & Leakages

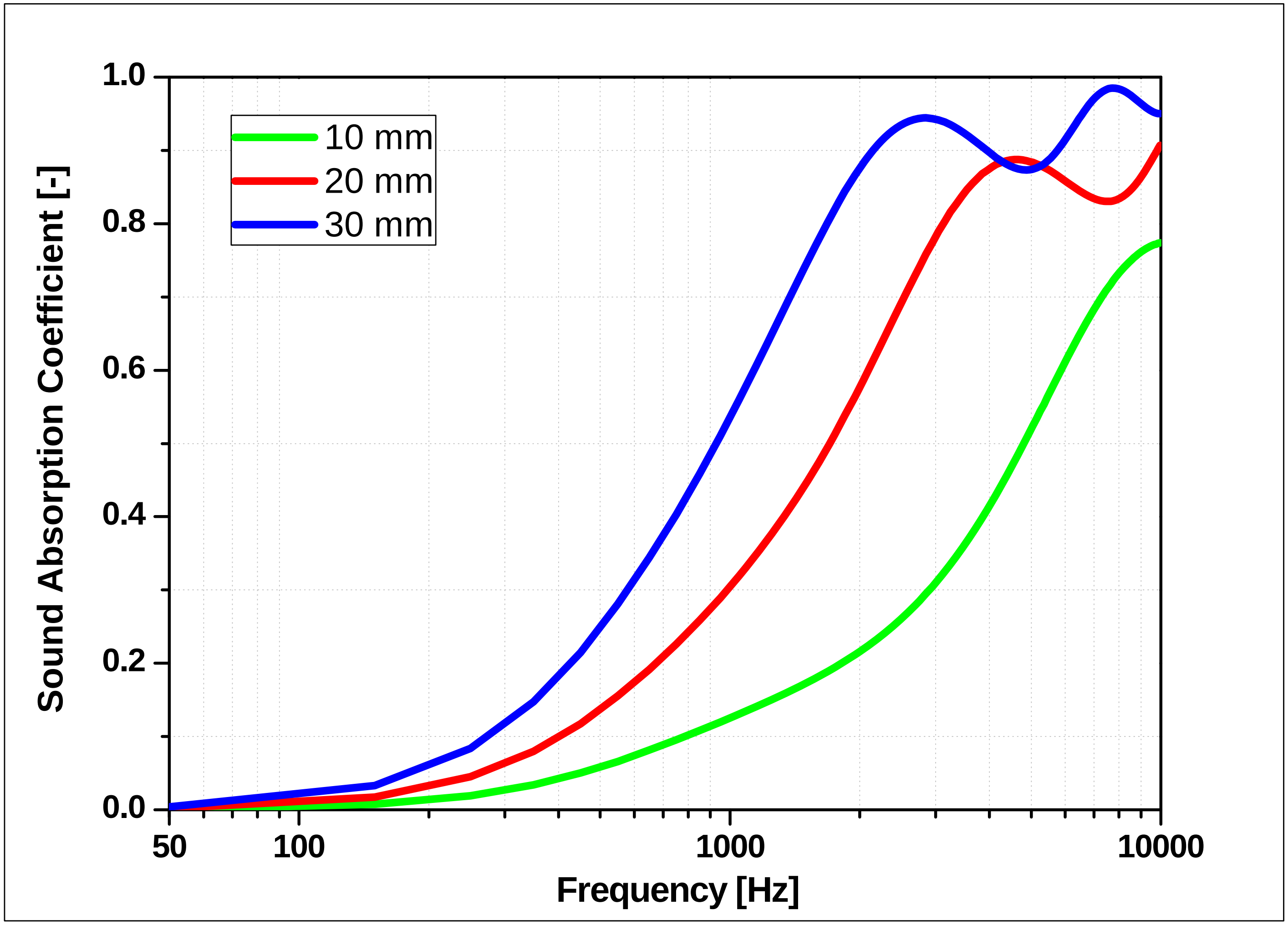
- Leaks are crucial role in transmission path at mid/high frequencies
- Leaks are due to passthroughs, Boot liners, etc.



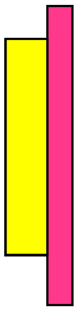


Effect of Thickness-Sound Absorption-Flow Resistivity 10 KN.S/m^4

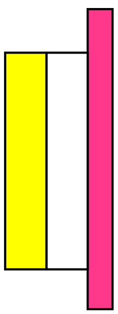




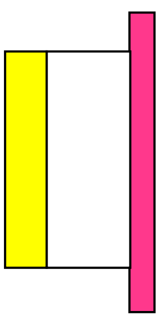
Effect of Air Gap-Sound Absorption- Thickness-10 mm



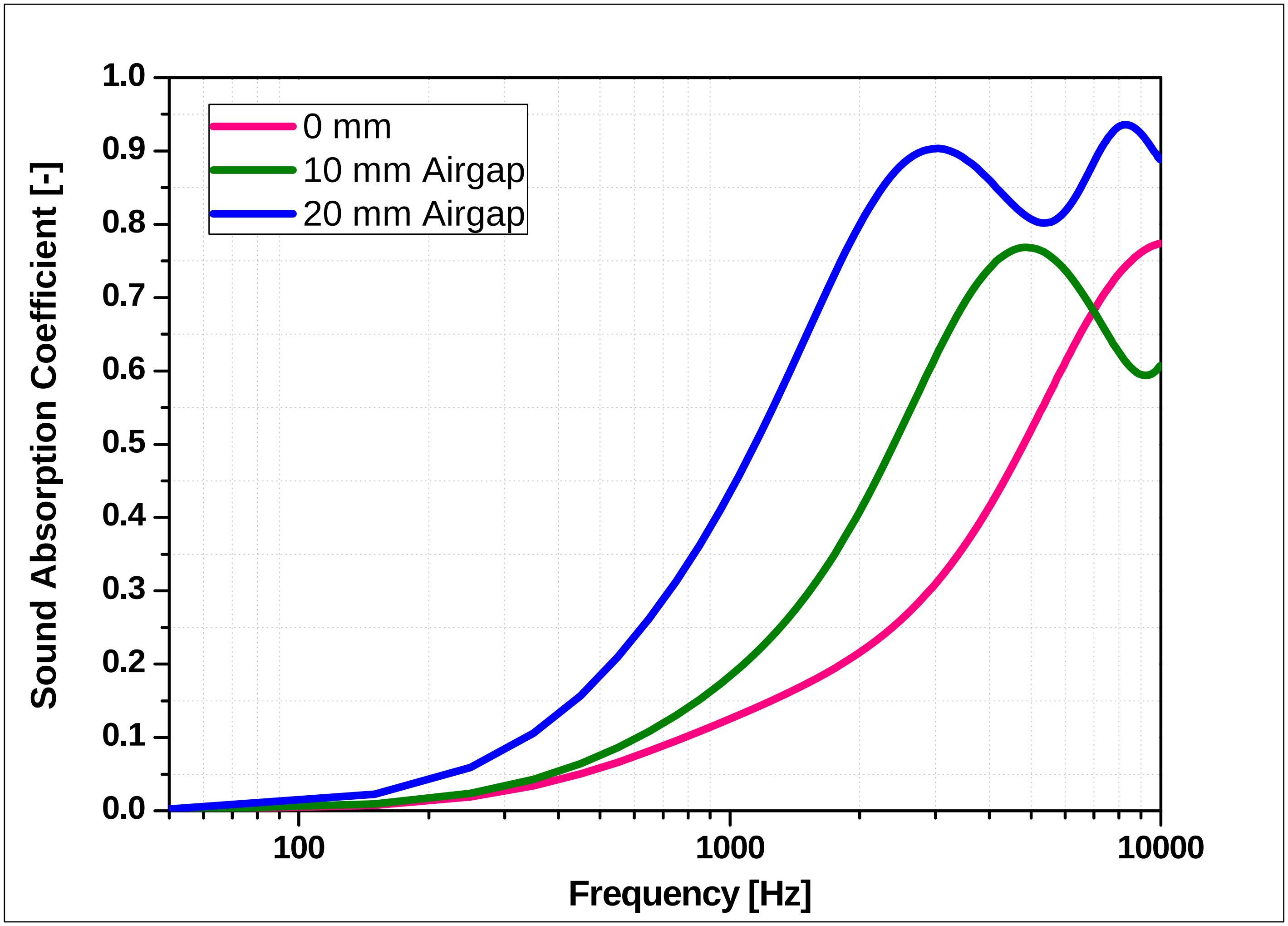
10 mm



10 + 10 mm

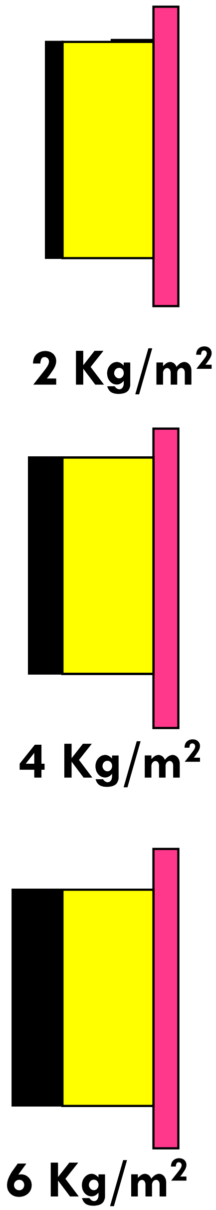


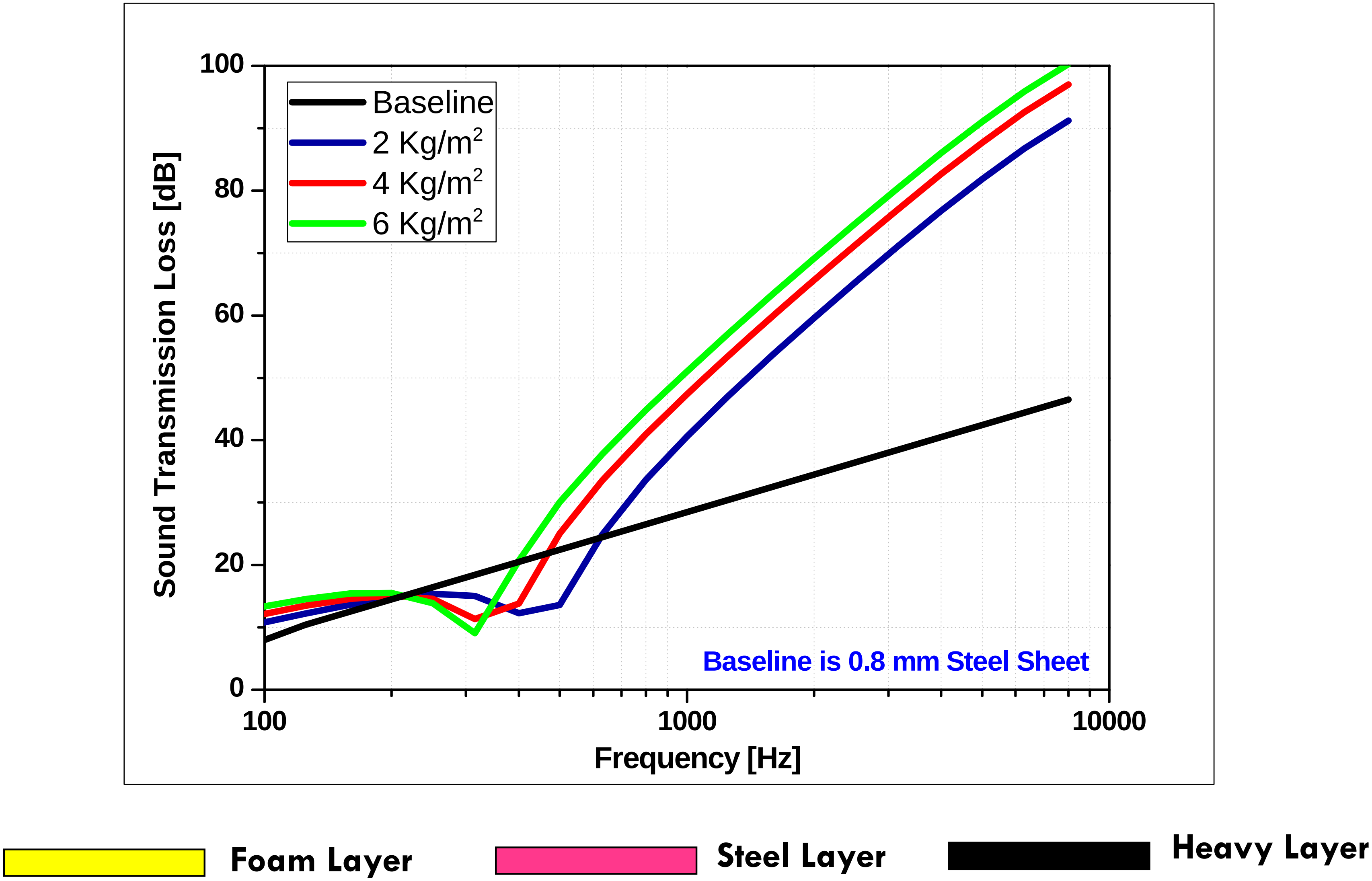
10+20 mm



Foam Layer Steel Layer Air

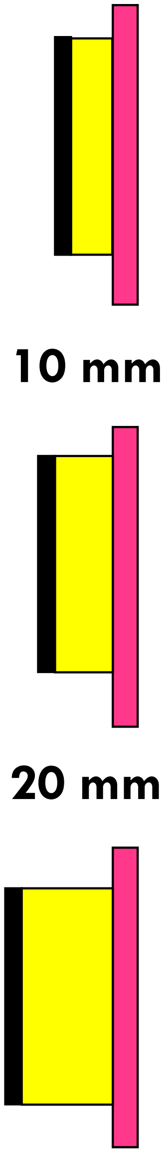
Effect of Mass-Sound Transmission Loss-Thickness-20 mm





Effect of Thickness-Sound Transmission Loss-

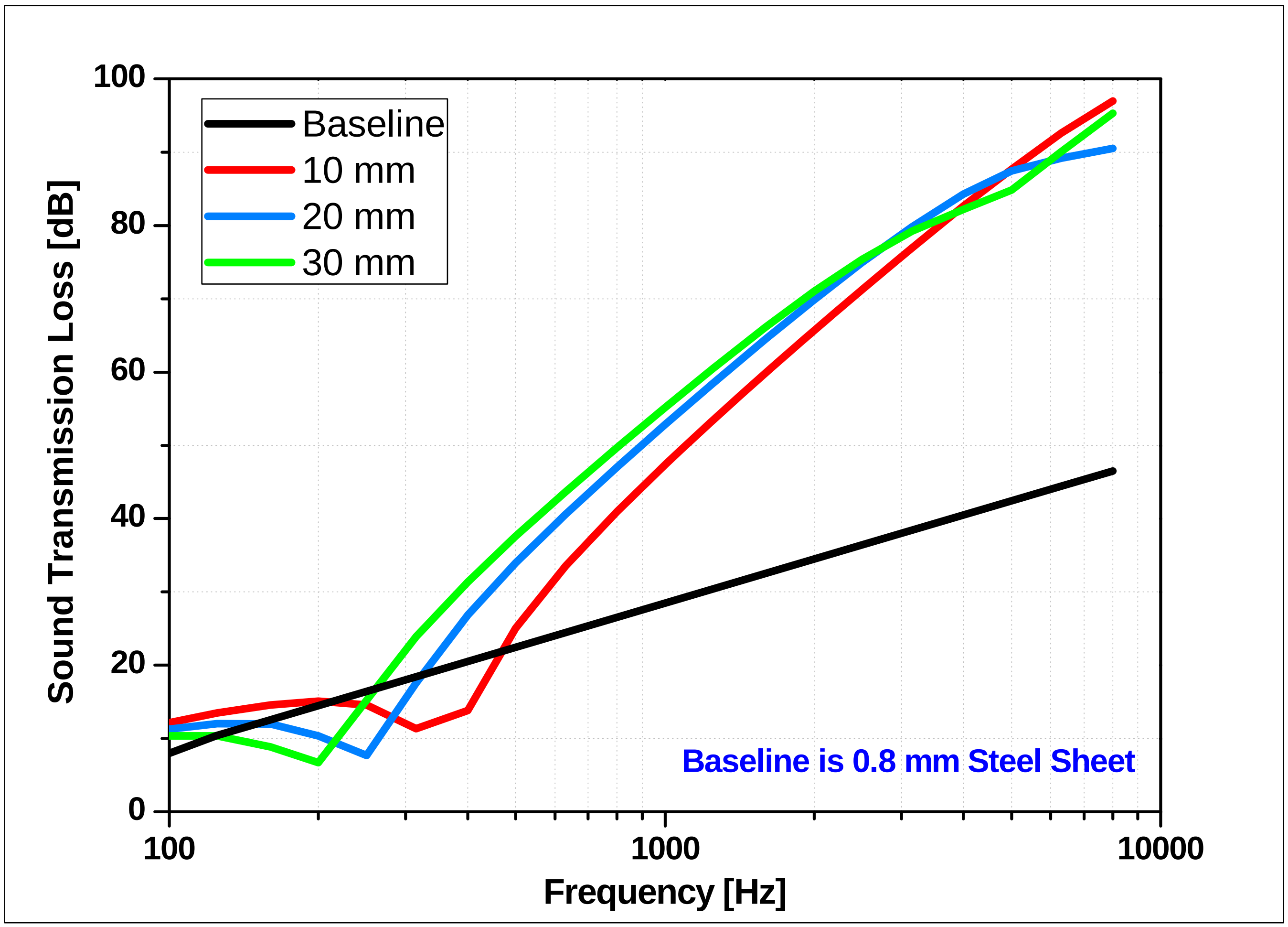
Flow Resistivity-25 KN.s/m^4



10 mm

20 mm

30 mm

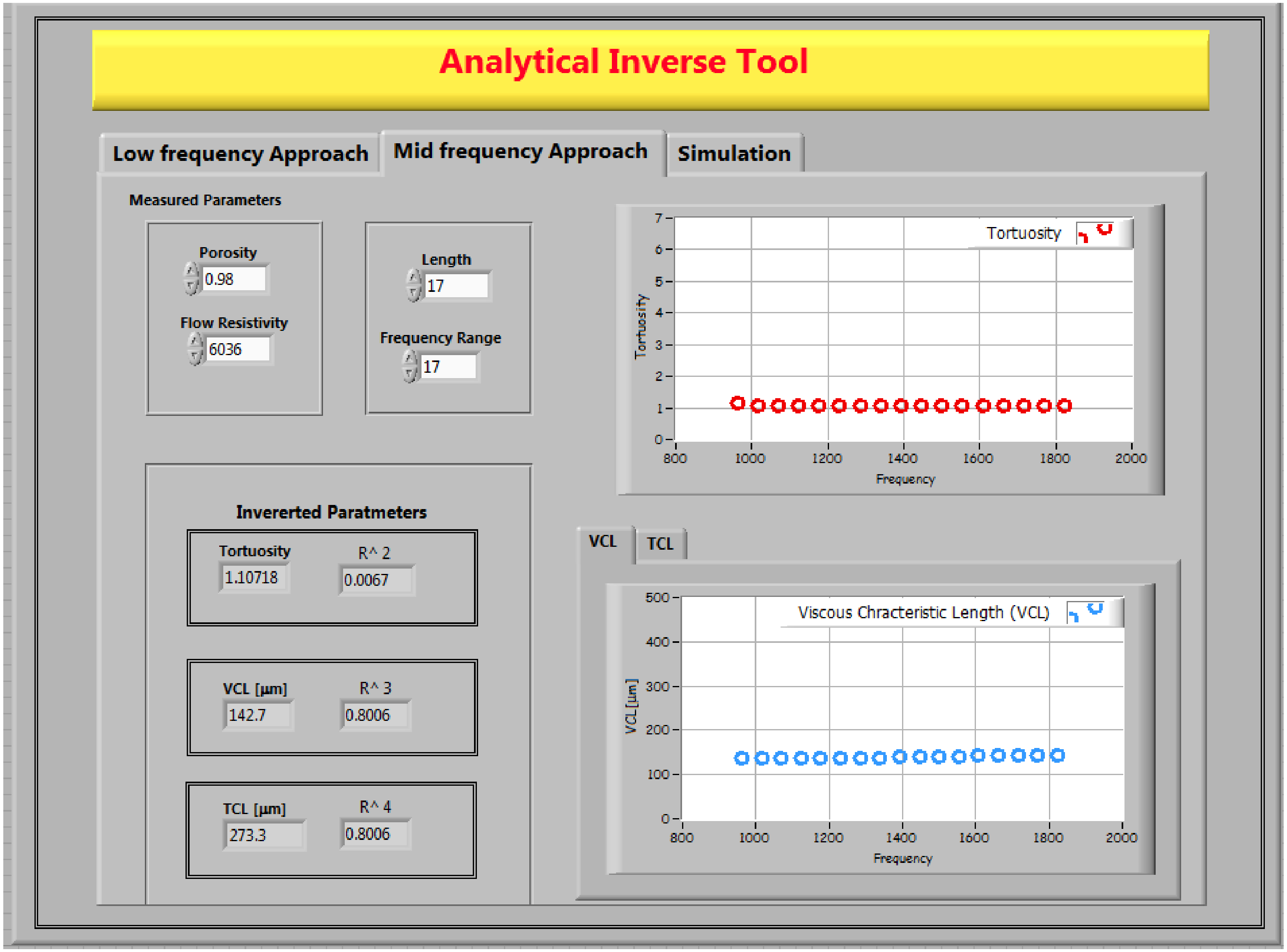


Foam Layer

Steel Layer

Heavy Layer

Analytical Inverse Characterization-GUI



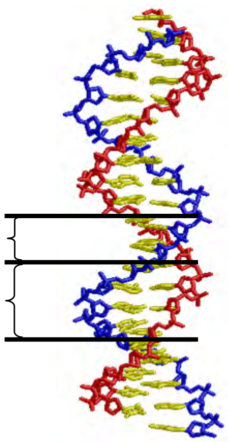
Optimization Inverse Method-Genetic Algorithm- GUI

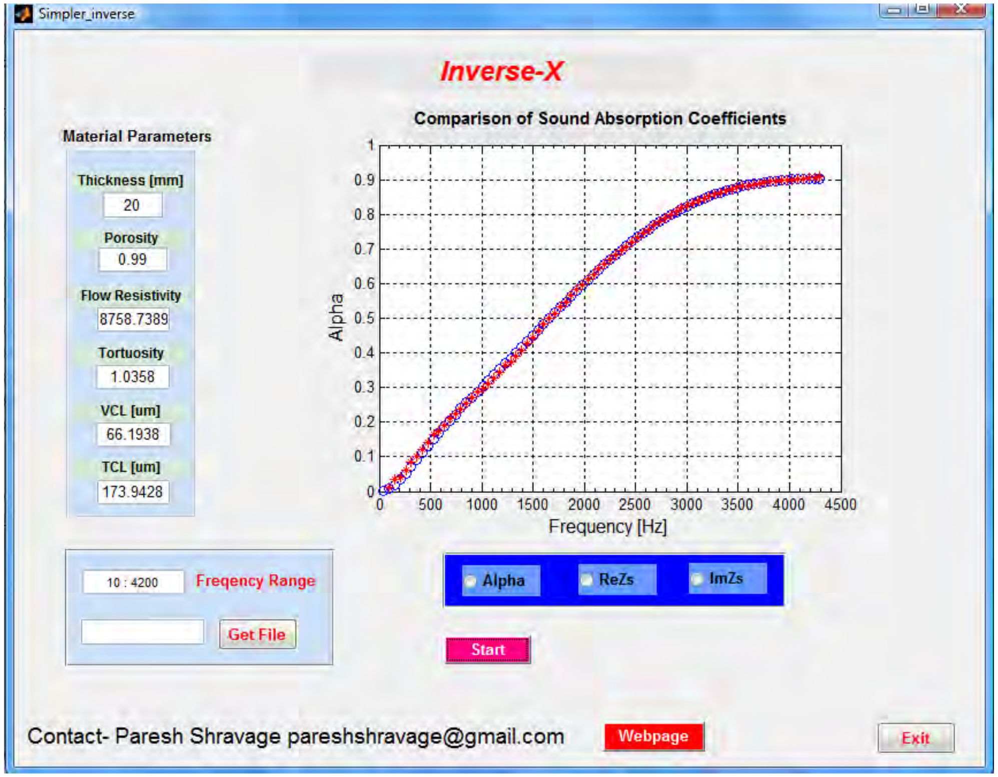
Natural Selection

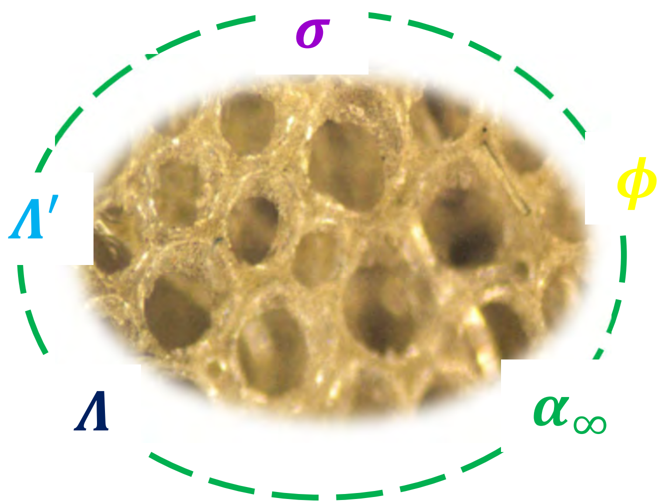
Genetic Code (DNA):

Charact. A

Charact. B





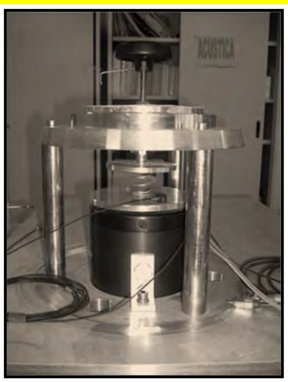


Acoustic Material Database

Porosity

Tortuosity

Quasi-static Mechanical Analyzer



Foam

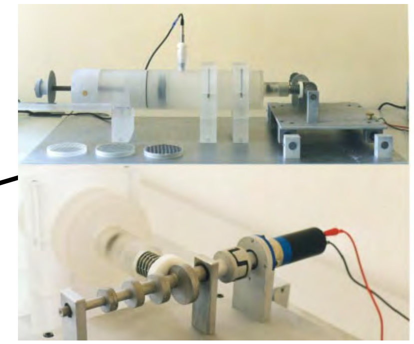
Name: Melamine foam - 8.8 kg/m3

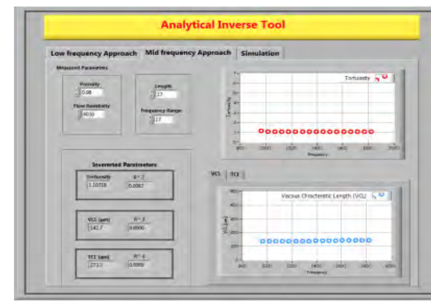
Properties

Density	8.8	kg / m3
Flow Resistivity	10900	kg / m3 s
Porosity	0.99	
Tortuosity	1.02	
Viscous c.l.	0.0001	m
Thermal c.l.	0.00013	m
Loss Factor	0.17	
Young's Modulus	80000	Pa
Poisson's Ratio	0.4	

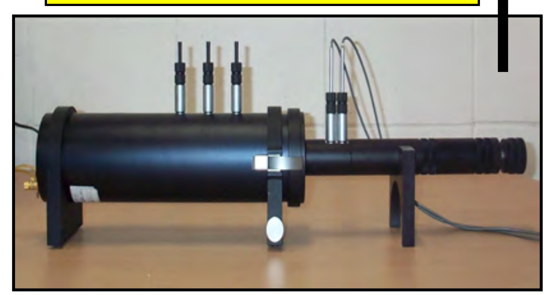
OK | Cancel | Help

Flow Resistivity

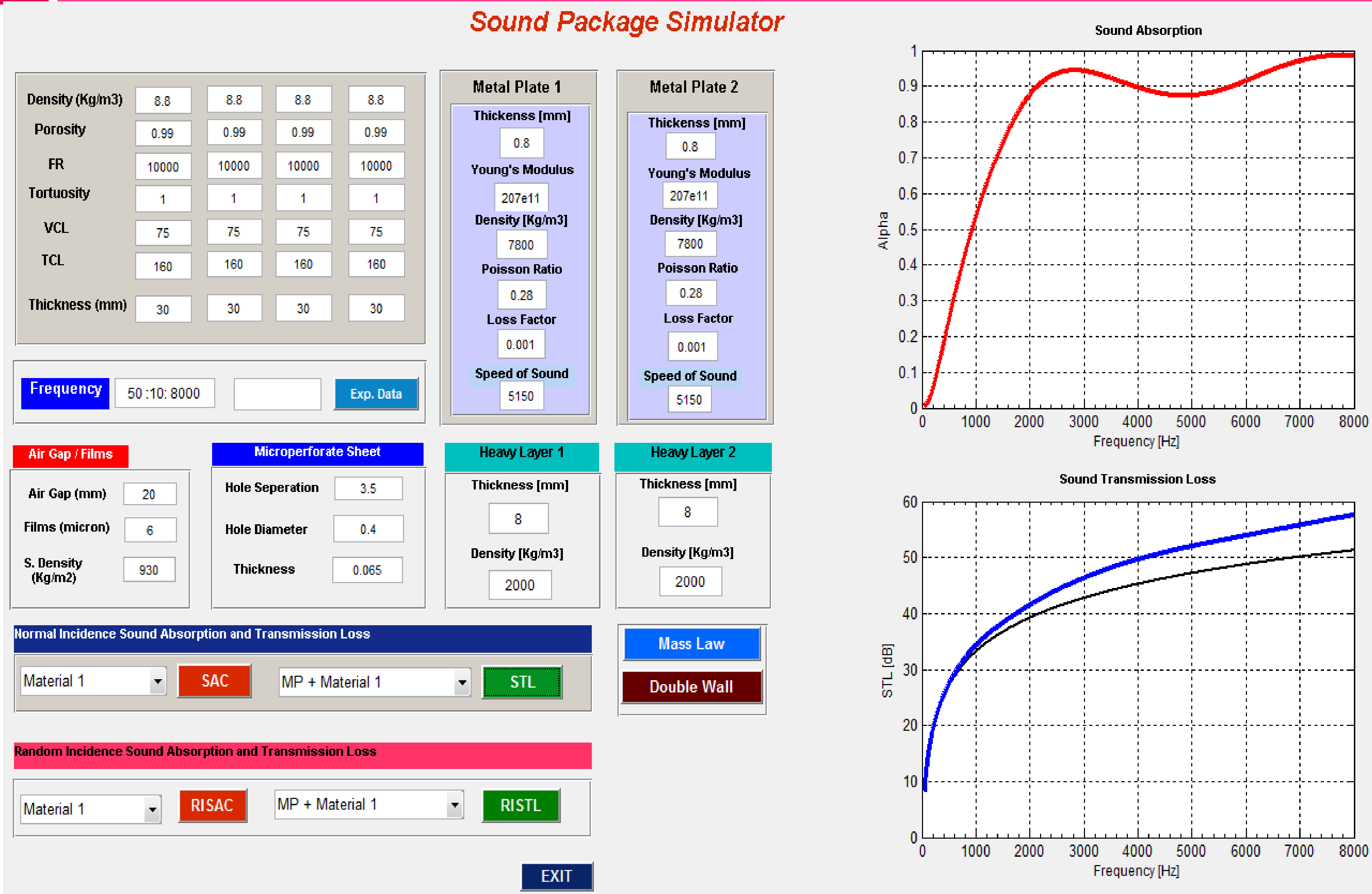




Inverse from Impedance Tube Measurement

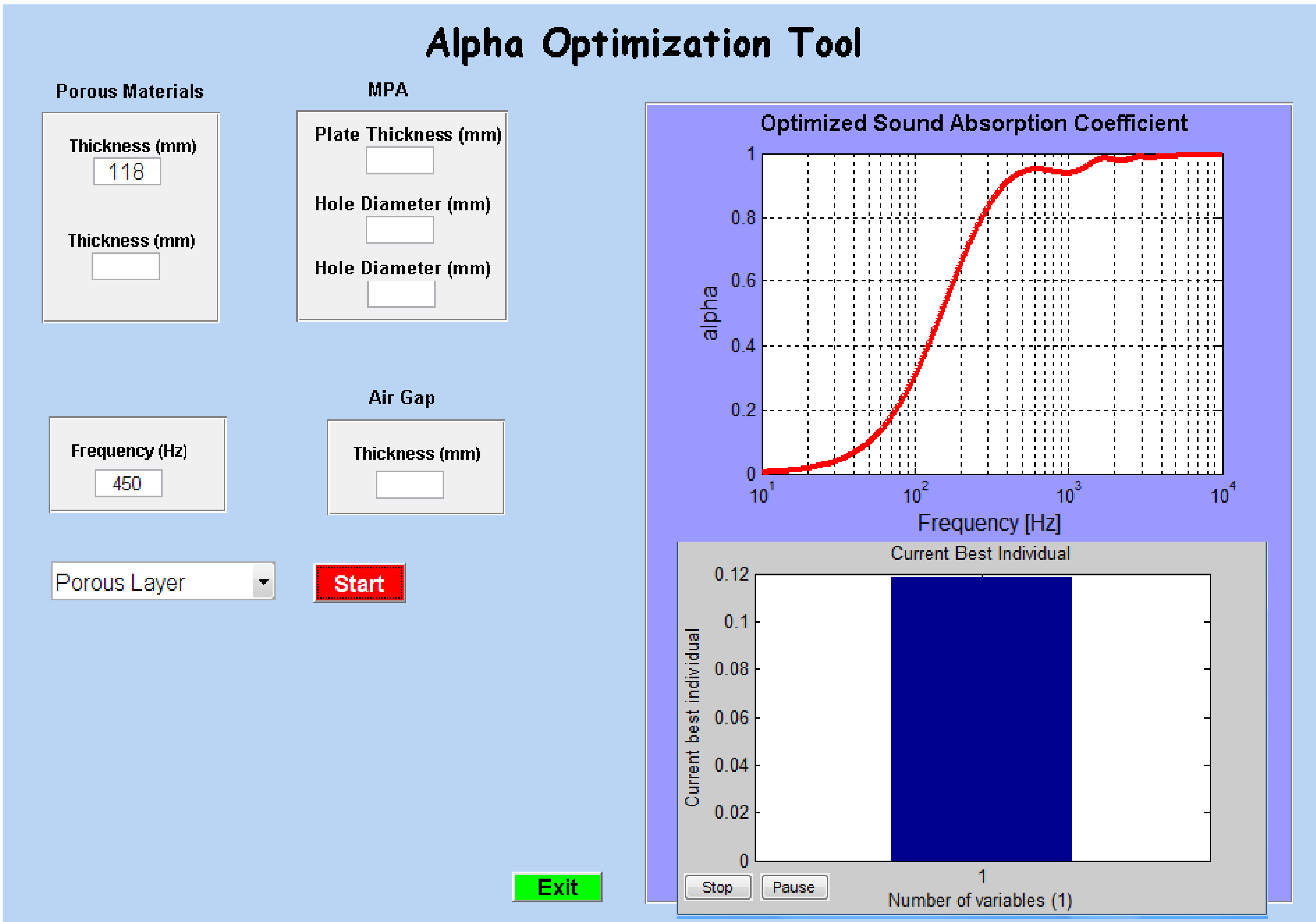


Acoustic Material Modelling

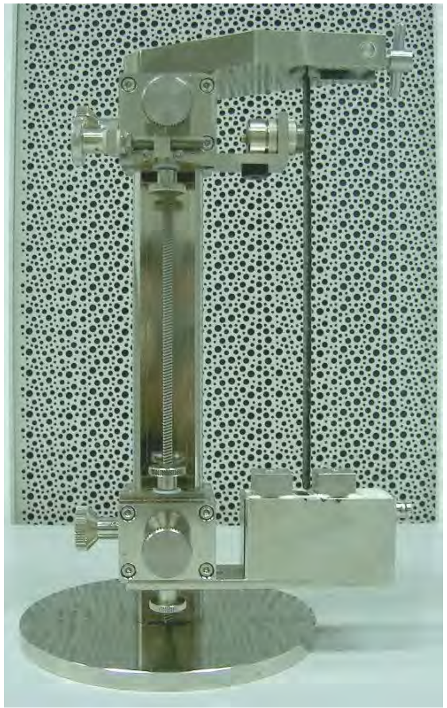


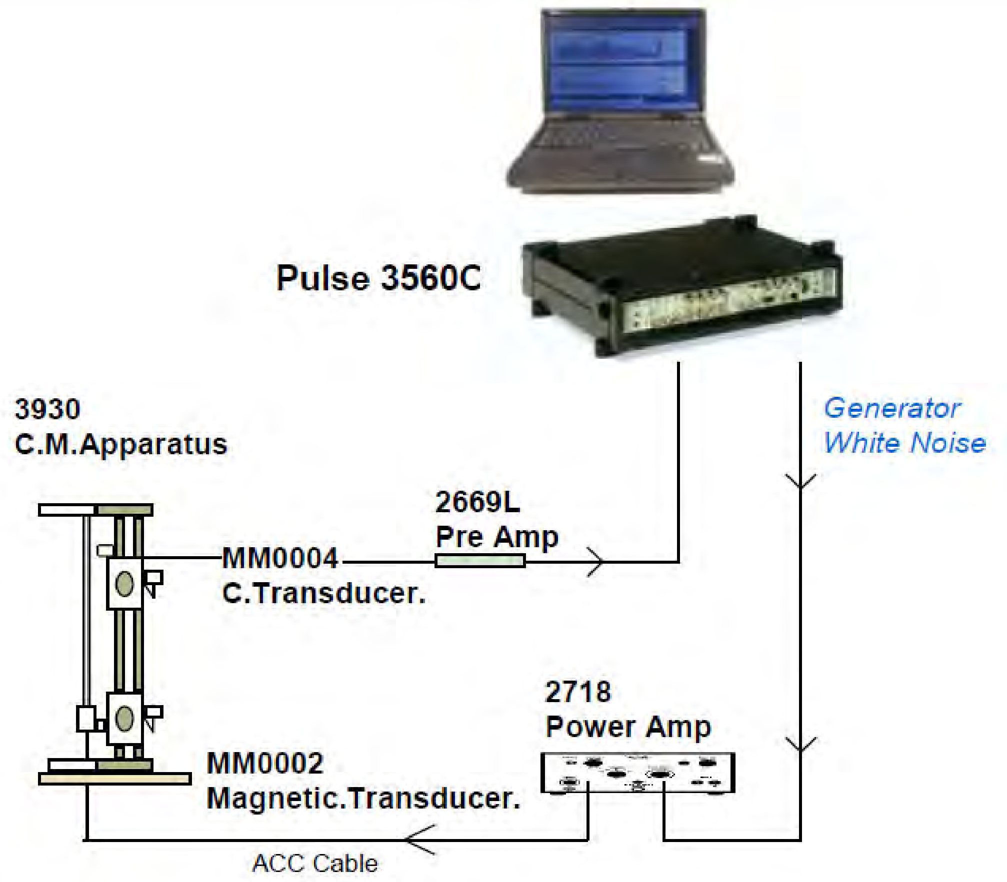
Optimization of Sound Package-Multilayers

- Optimization Tool for optimizing thickness constraints on Materials for Higher Sound Absorption



Oberst Bar setup for Damping

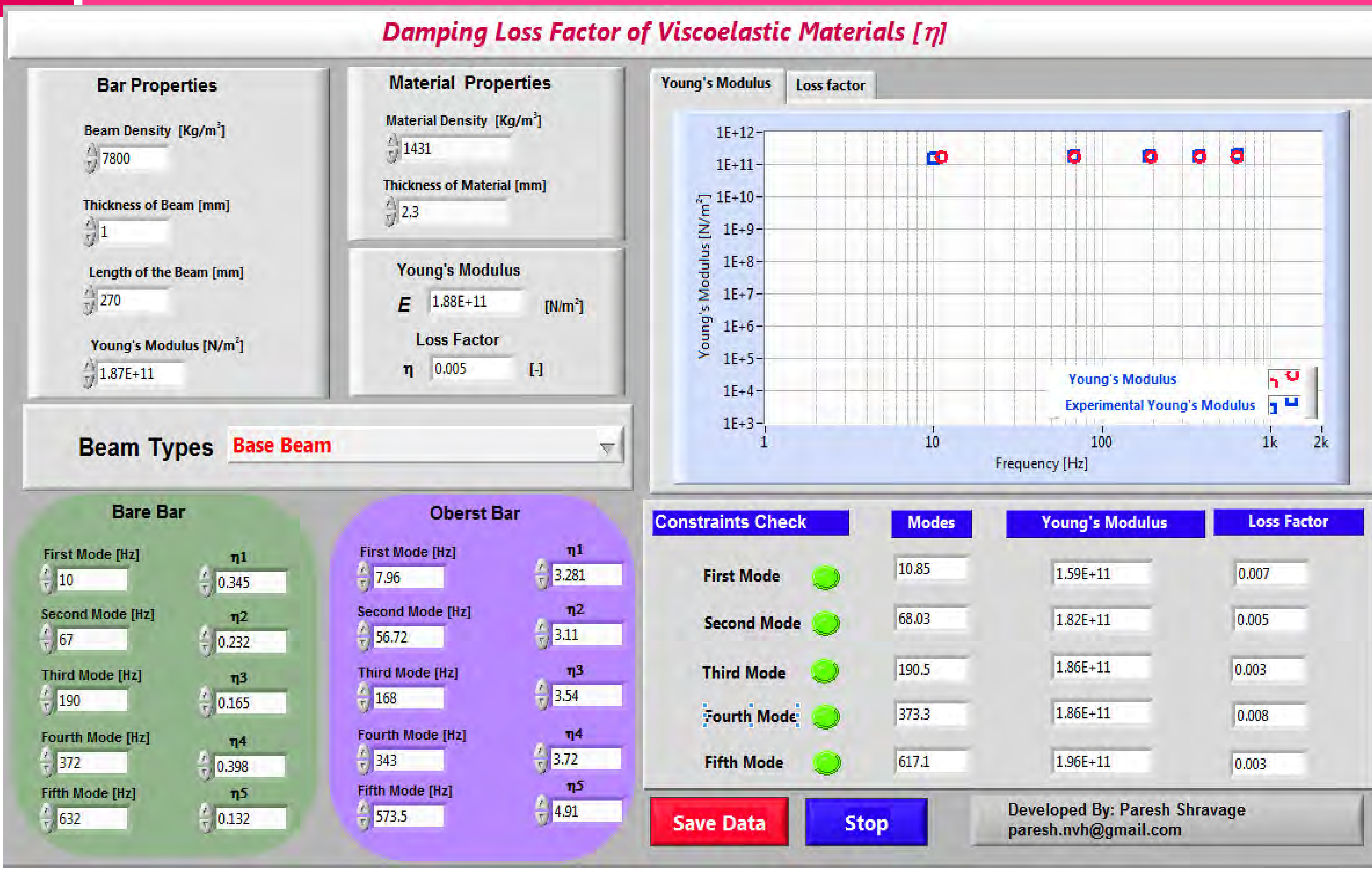




Unconstrained layer – Free layer

Constrained layer – Multi layer

GUI for Oberst Bar Method



Let the Nobel Ideas come from all directions...

Thank You for your time!

If you are intereted in my profile, plese contact me on...

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