Acoustic Material Testing - Impedance Tube and Standards

Dr. Paresh Shravage

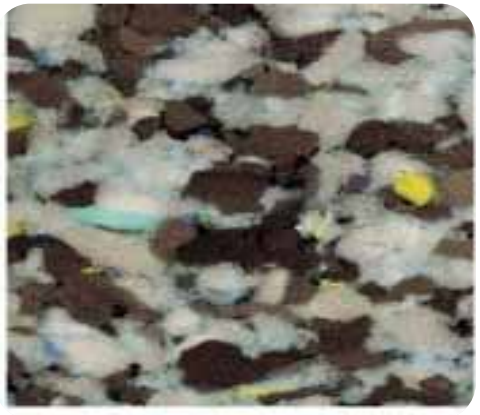
Alfa Acoustics
Silence through Science
An ISO 9001:2015 Company

Outline -

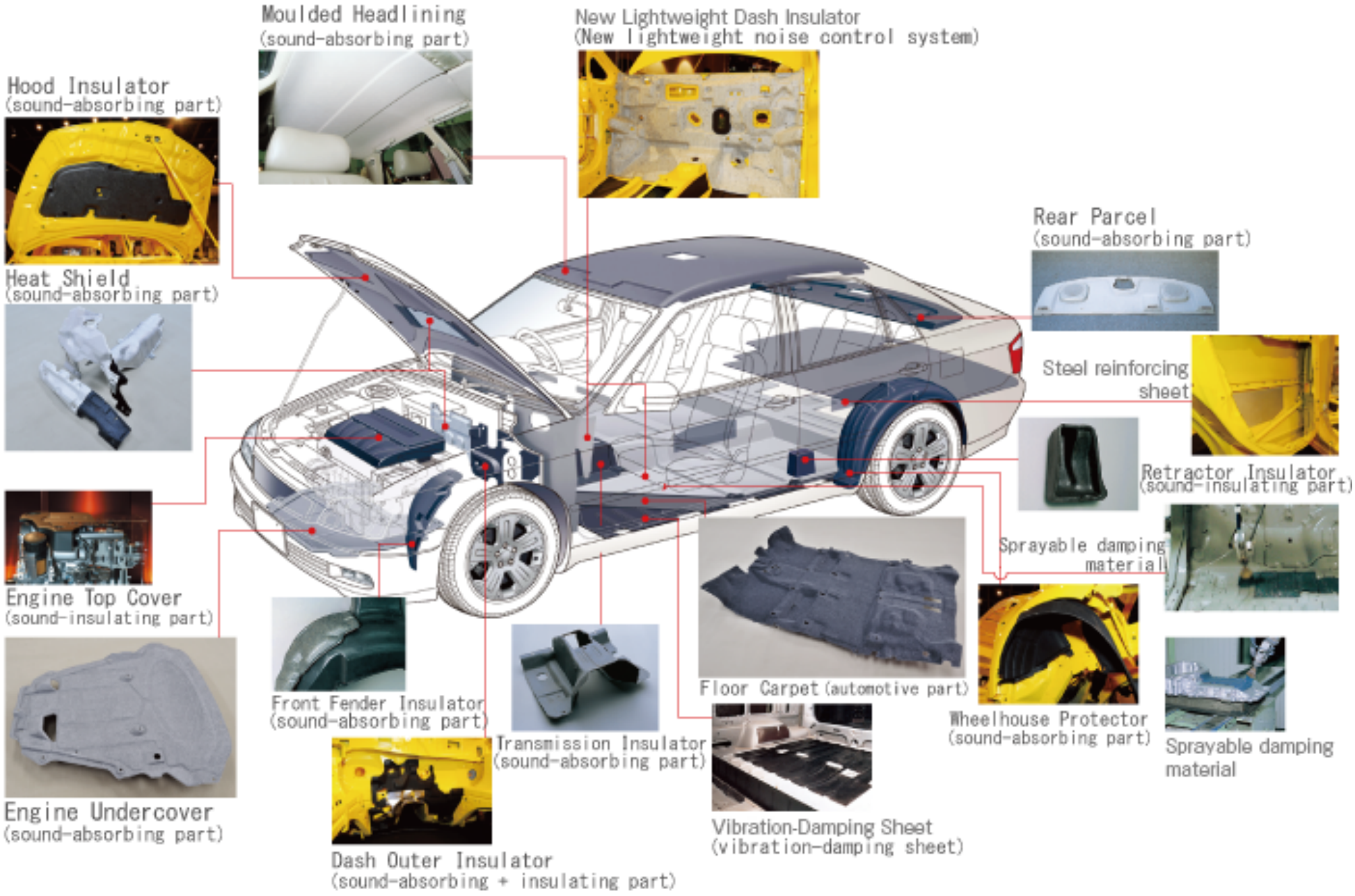
- Acoustic materials, types
- Acoustic material applications-Automotive and Architectural
- Sound absorption coefficient
- Sound transmission loss
- Testing methods
- Sample preparation
- Test standards
- Impedance tube Testing

Acoustic Materials -

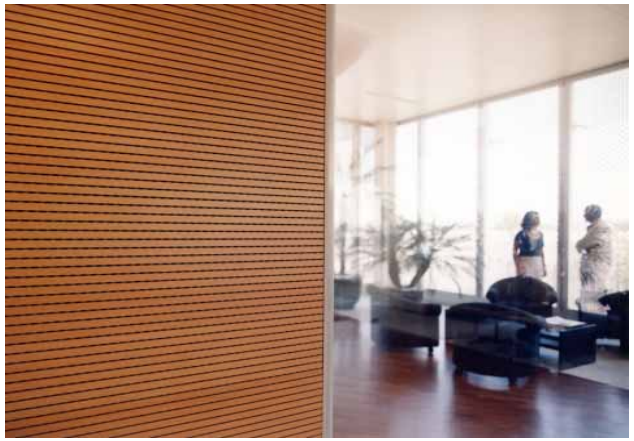
- Porous Foams - e.g. Melamine, Polyurethane
- Fibrous Materials- e.g. Glass Wool, Fiberform
- Felts (Recycled Materials)- e.g. Nonwovens, PET Felts
- Perforated and Microperforated materials

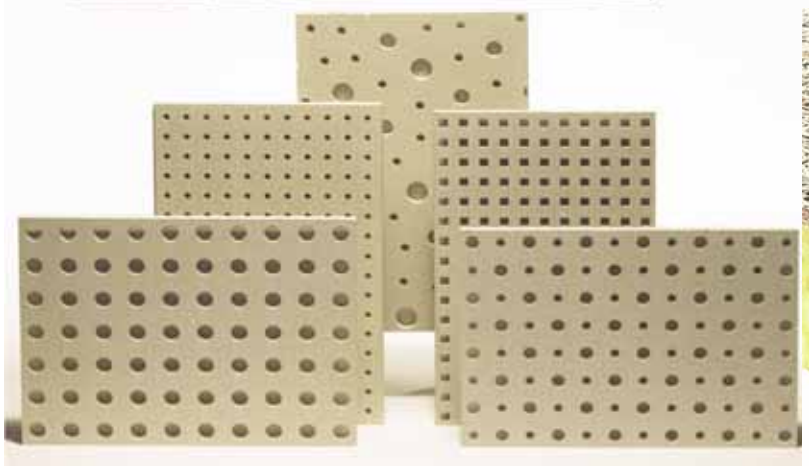


Acoustic Material Applications-Automotive



Acoustic Material Applications-Architectural

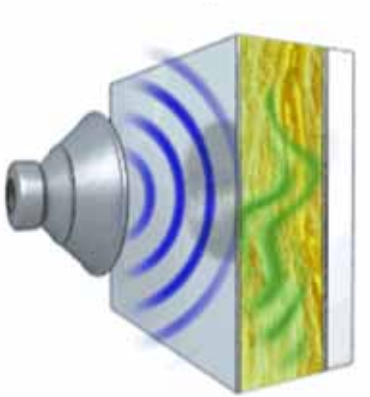




Sound Absorption Coefficient [SAC] -

- 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.

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



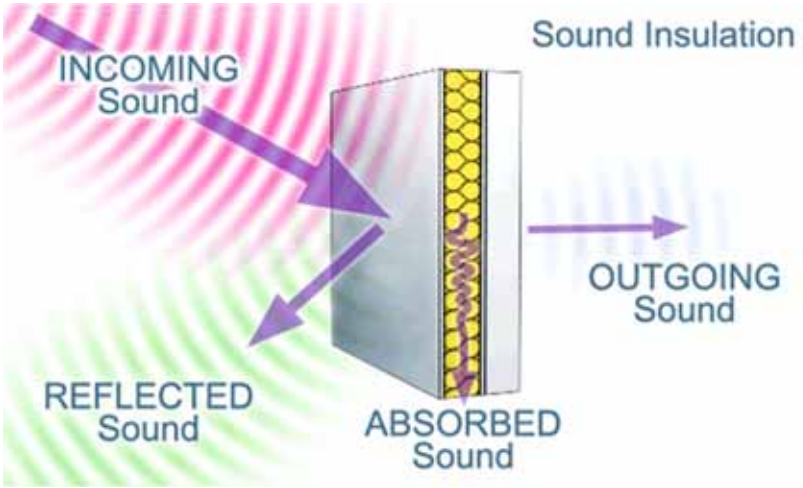
- Normal incidence sound absorption coefficient-Two Microphone Tube
- Random incidence sound absorption coefficient-Reverberation Suite

Sound Transmission Loss -

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

$$\tau = \frac{Sound\ Power\ Transmitted}{Sound\ Power\ Incident}$$

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



- Normal incidence sound transmission loss -Two Microphone Tube
- Random incidence sound transmission loss -Reverberation Suite

Test Standards -

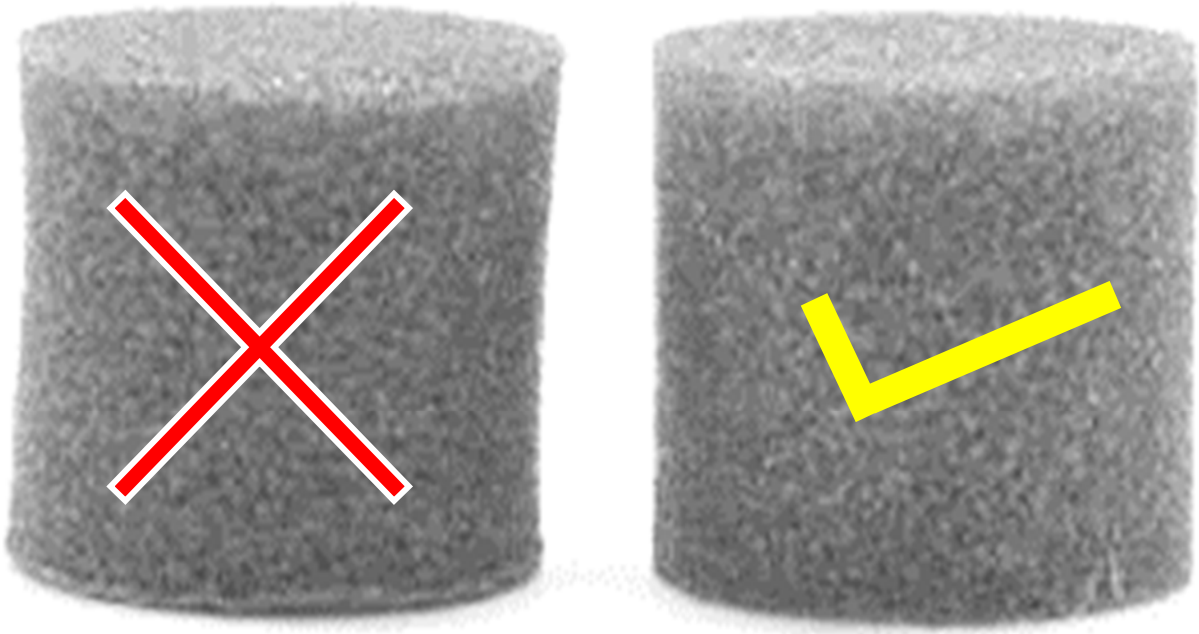
- **Two-microphone Impedance Tube Method**
  - **ISO 10534-2: 1998-** Acoustics - Determination of sound absorption coefficient and impedance in impedance tubes - Part 2: Transfer function method
  - **ASTM E1050:2019-** Standard Test Method for Impedance and Absorption of Acoustical Materials Using A Tube, Two Microphones and A Digital Frequency Analysis System
  - **JIS A 1405-2:2007 -** Acoustics - Determination Of Sound Absorption Coefficient And Impedance In Impedance Tubes - Part 2: Transfer-function Method

- **Four-microphone Impedance Tube Method**
  - ASTM E2611: Standard Test Method for Normal Incidence Determination of Porous Material Acoustical Properties Based on the Transfer Matrix Method

Sample Preparation -

- Precise sample cutting is required for accurate results
  - ✓ Waterjet
  - ✓ Die Cut
  - ✓ Punch

Test Specimen - “Bad” and “Good”

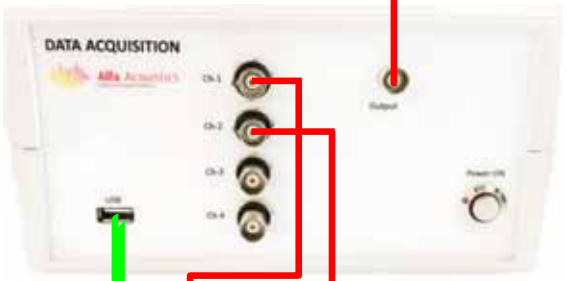


Impedance Tube-

Impedance Tube Set				
Tube	Large	Small	Medium	Medium
Internal Diameter (mm)	100	29	34.9	45
Sound Absorption Standards	ASTM E1050 / ISO 10534-2			
Sound Transmission Loss Standard	ASTM E2611			
Frequency Range (Hz)	100-1600	700-6300	200-5000	150-4500
Microphones	¼", Pressure Field – 4 Nos			
Loudspeaker	4" in diameter, 15 Watts, 6 Ohm			

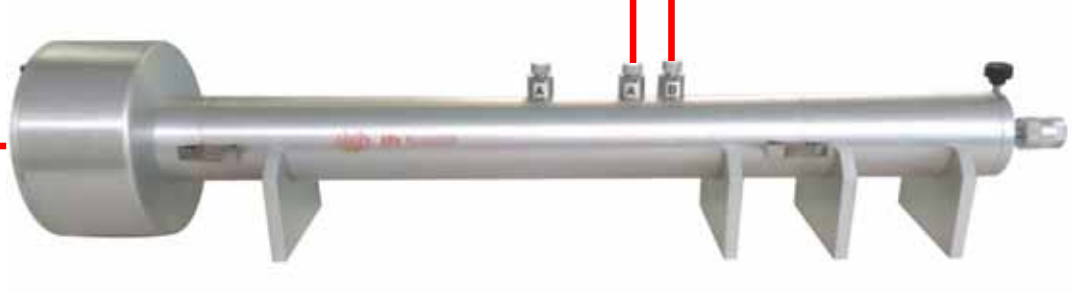
Impedance Tube – Sound Absorption Coefficient

Power Amplifier

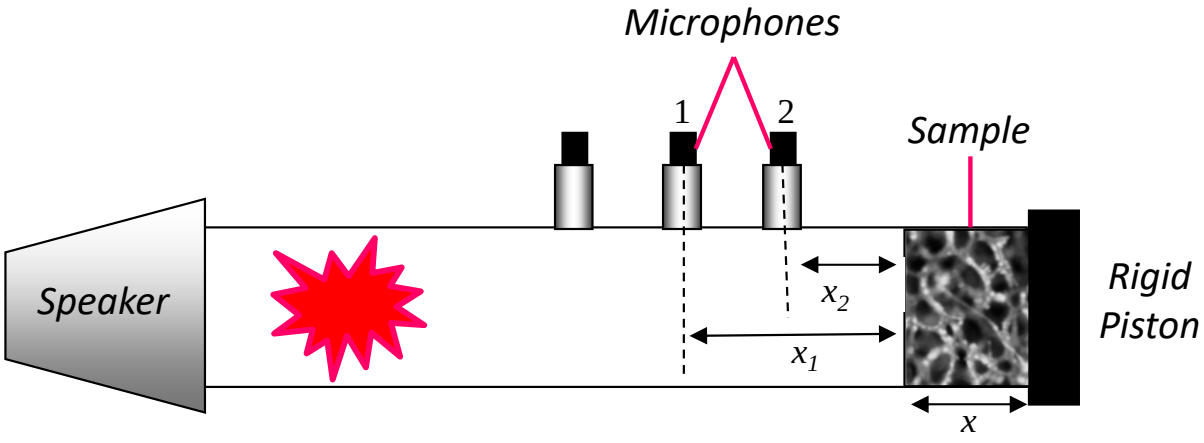


DAQ

Laptop with Software



Two microphone Impedance Tube



Test Samples

Impedance Tube –Plane Wave Theory

The sound pressures P_1 and P_2 in the two microphone positions are

$$P_1 = \hat{p}_1 e^{jkx_1} + \hat{p}_R e^{-jkx_1} \qquad P_2 = \hat{p}_2 e^{jkx_2} + \hat{p}_R e^{-jkx_2}$$

The transfer function for the incident wave alone H_I is:

$$H_I = \frac{P_{2I}}{P_{1I}} = e^{-jk(x_1 - x_2)} = e^{-jks} \qquad where\ s = (x_1 - x_2)\ is\ the\ seperation\ between\ microphones$$

Similarly, the transfer function for the reflected wave alone H_R is:

$$H_R = \frac{P_{2R}}{P_{1R}} = e^{-jk(x_1 - x_2)} = e^{-jks}$$

The transfer function $H12$ for the total sound field may now be obtained by

$$H_{12} = \frac{P_2}{P_1} = \frac{e^{jkx_2} + Re^{-jkx_2}}{e^{jkx_1} + Re^{-jkx_1}} \qquad where\ R = \frac{P_R}{P_I}\ is\ the\ Reflection\ coefficient$$

Impedance Tube –Plane Wave Theory

Solving for *R*:

$$R = \frac{H_{12} - H_I}{H_R - H_{12}} e^{2jkx_1}$$

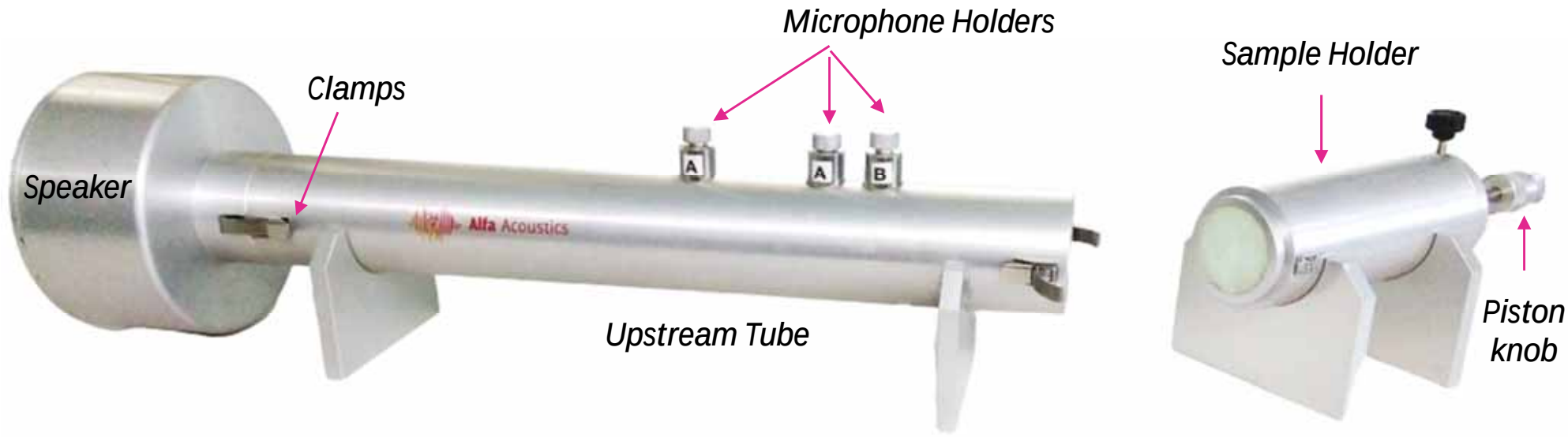
Sound absorption coefficient (α)

$$\alpha = 1 - |R|^2$$

Normalized specific boundary impedance:

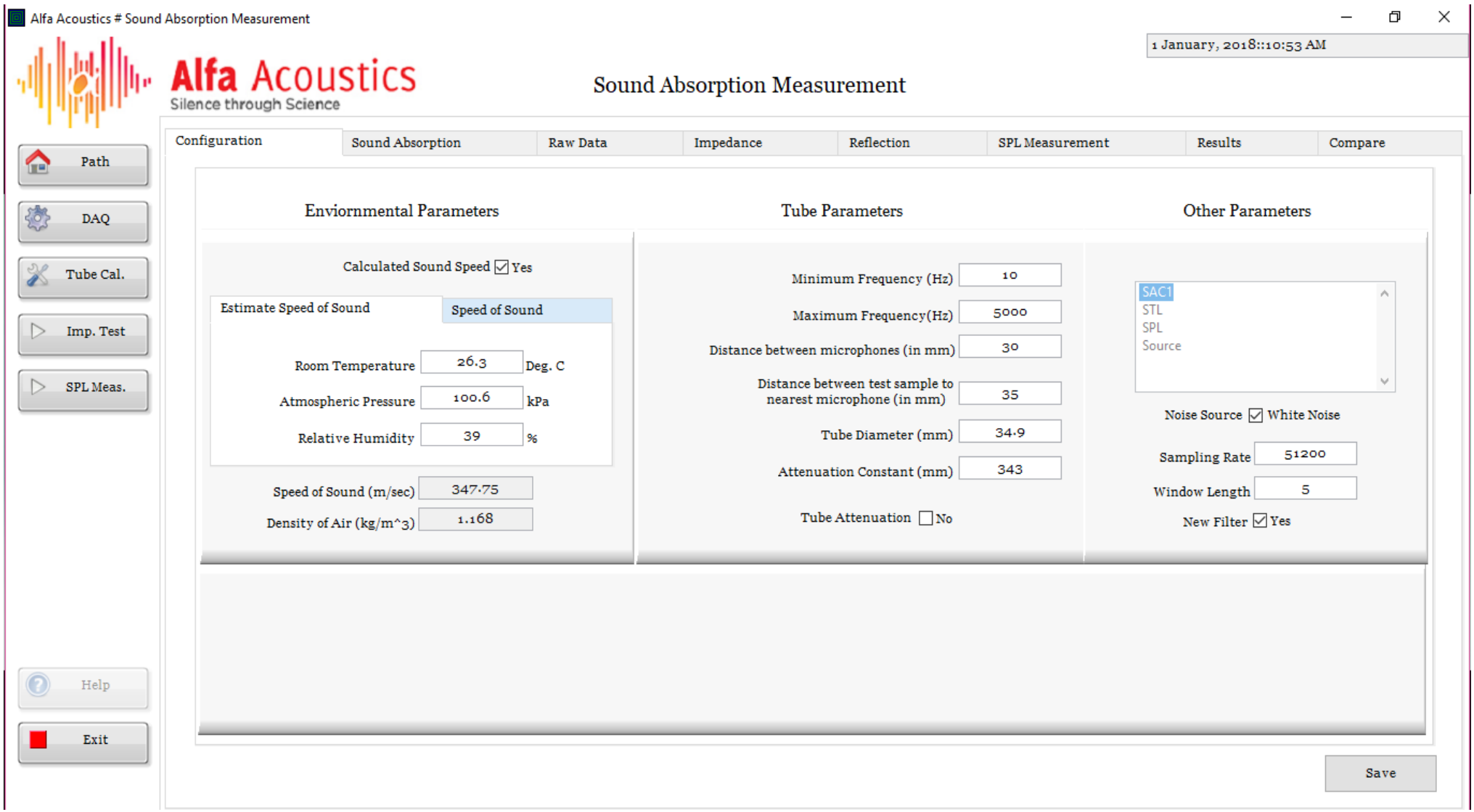
$$\frac{z}{\rho_0 c} = \frac{1+R}{1-R}$$

Sound Absorption Measurement -

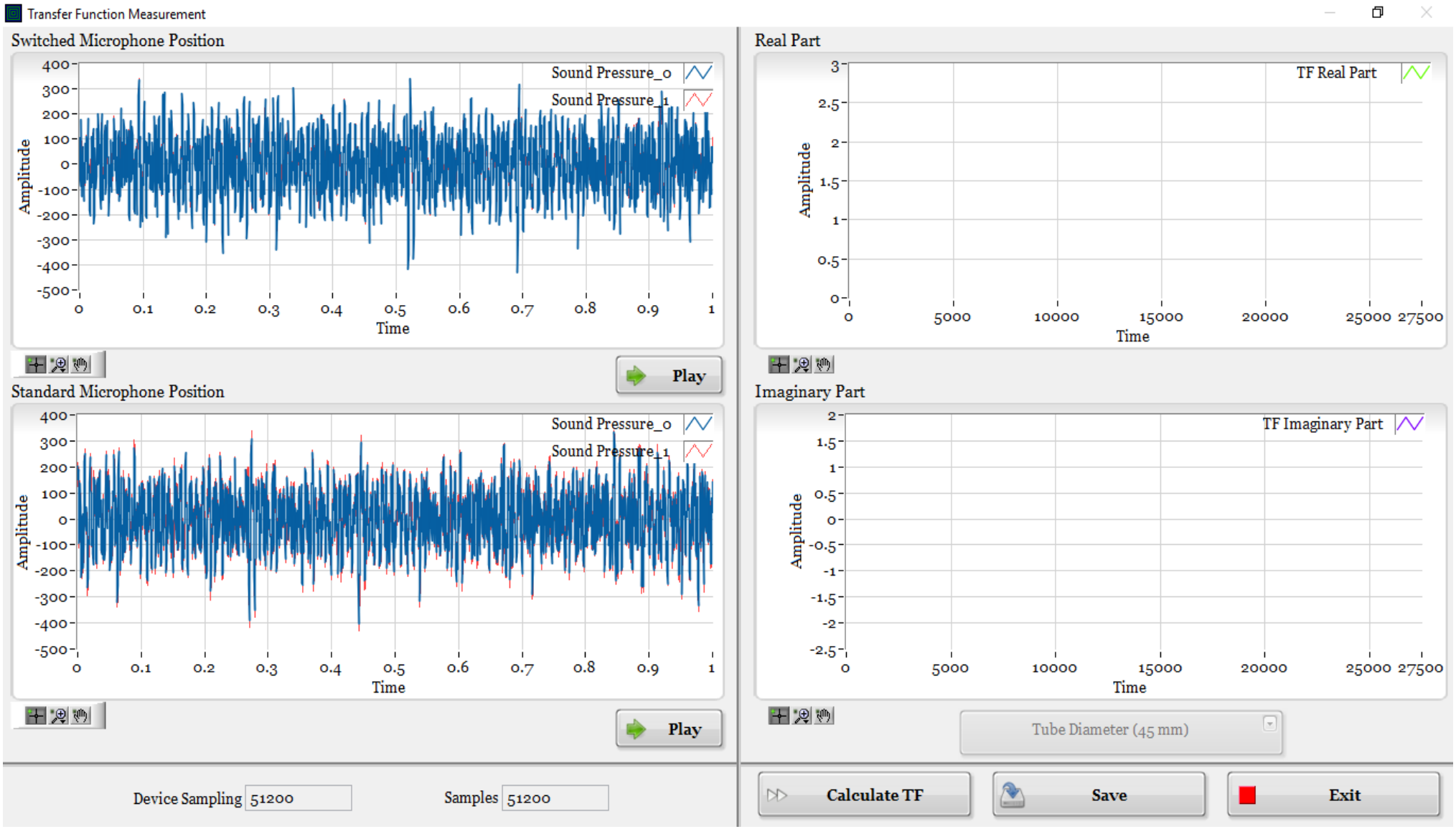


Sample Holder with sample

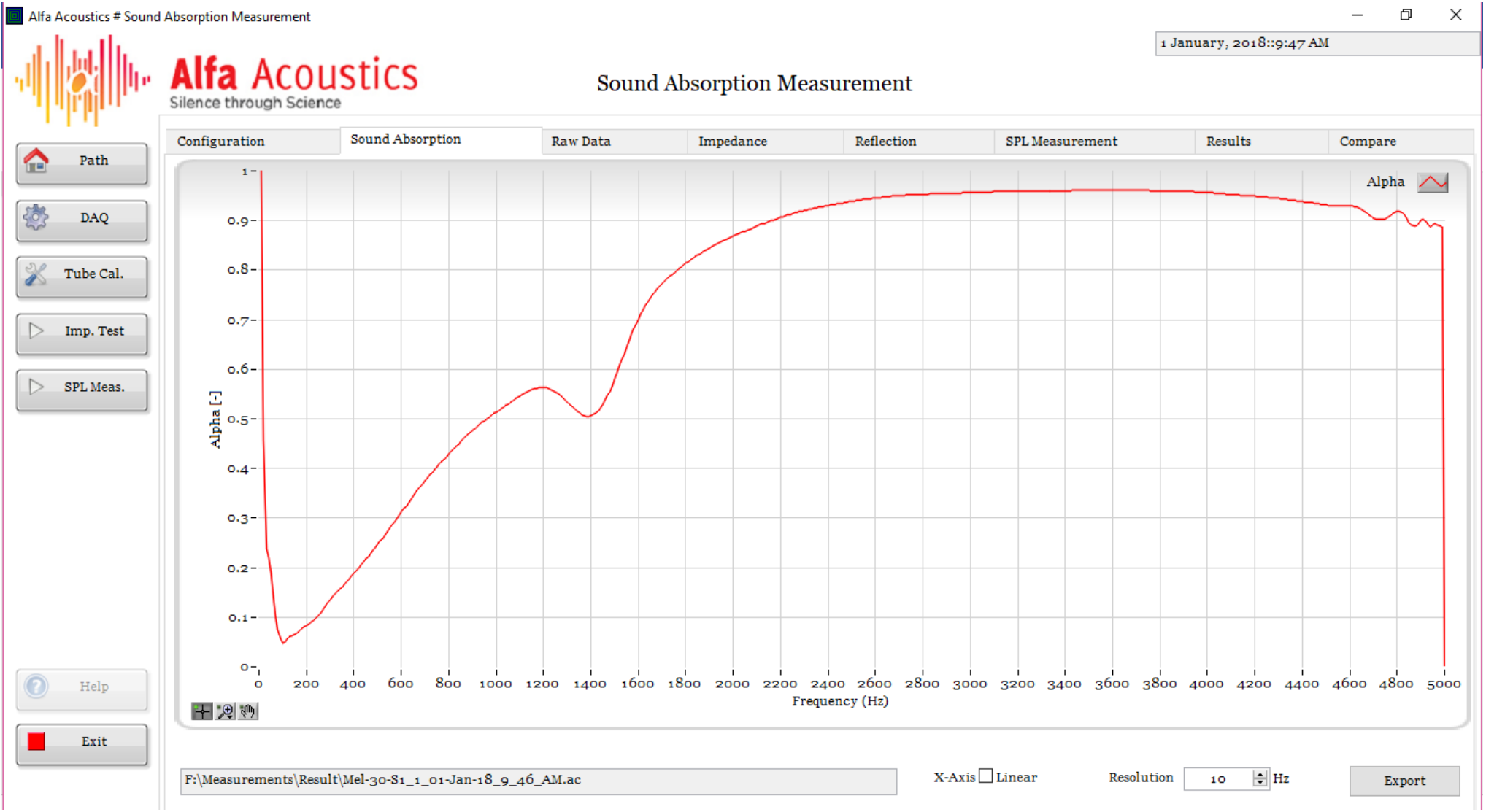
Sound Absorption –Software Interface



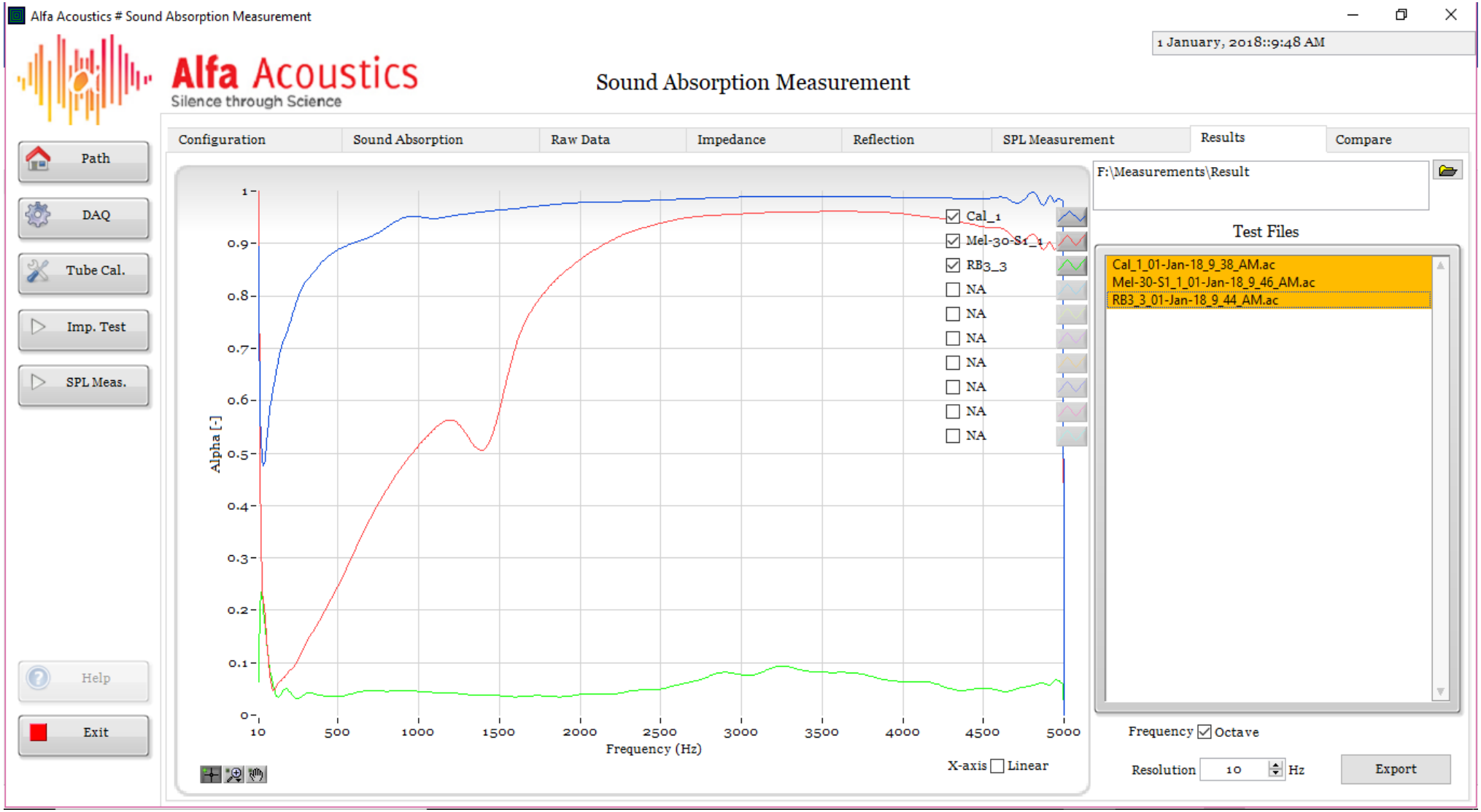
Sound Absorption Software – Calibration



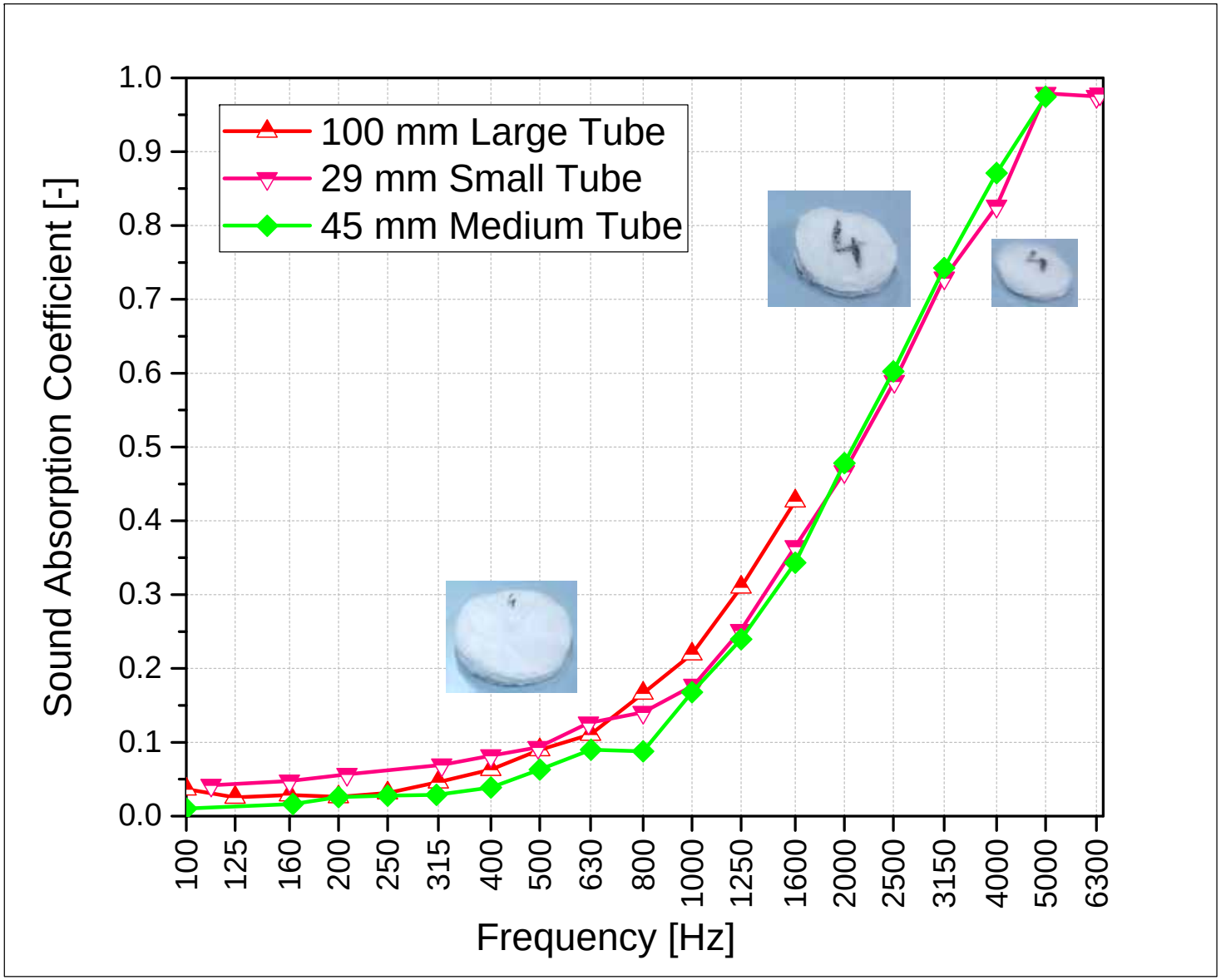
Sound Absorption Software – Measurement



Sound Absorption Software – Result Export

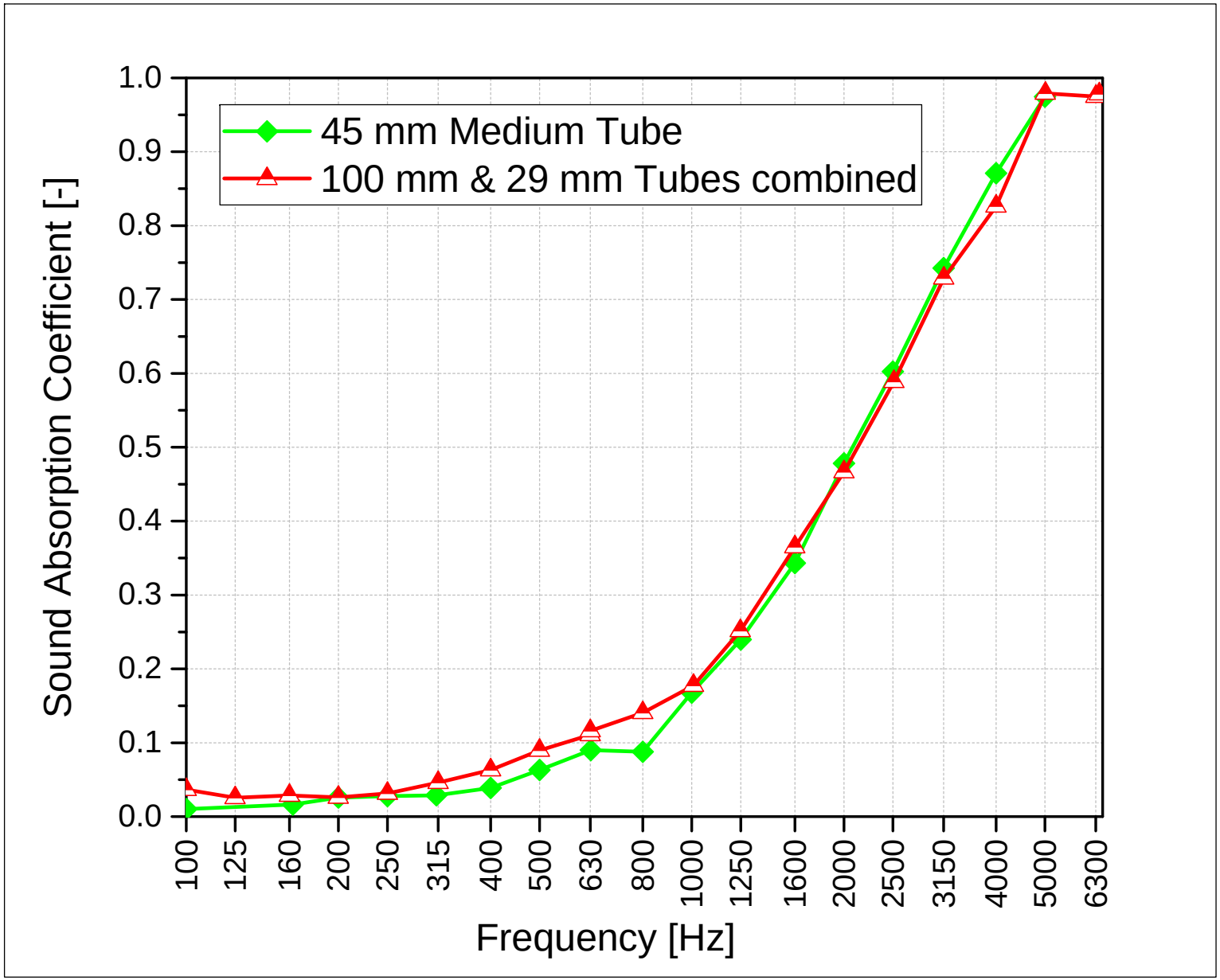


Impedance Tube – Why 45 mm Tube for Industry?

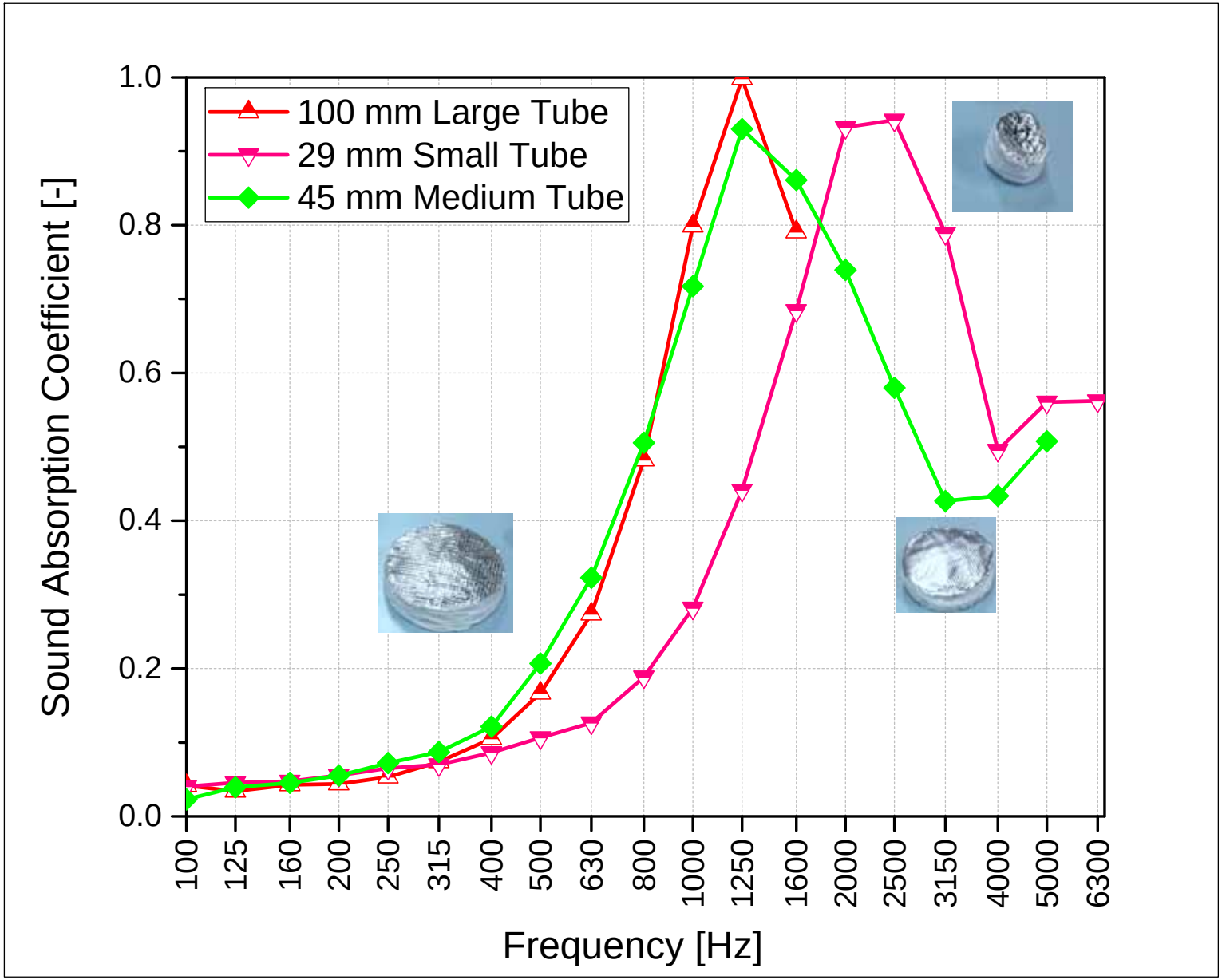


If sample is homogenous and single layer, then results from tubes will be similar

Impedance Tube – Why 45 mm Tube for Industry?

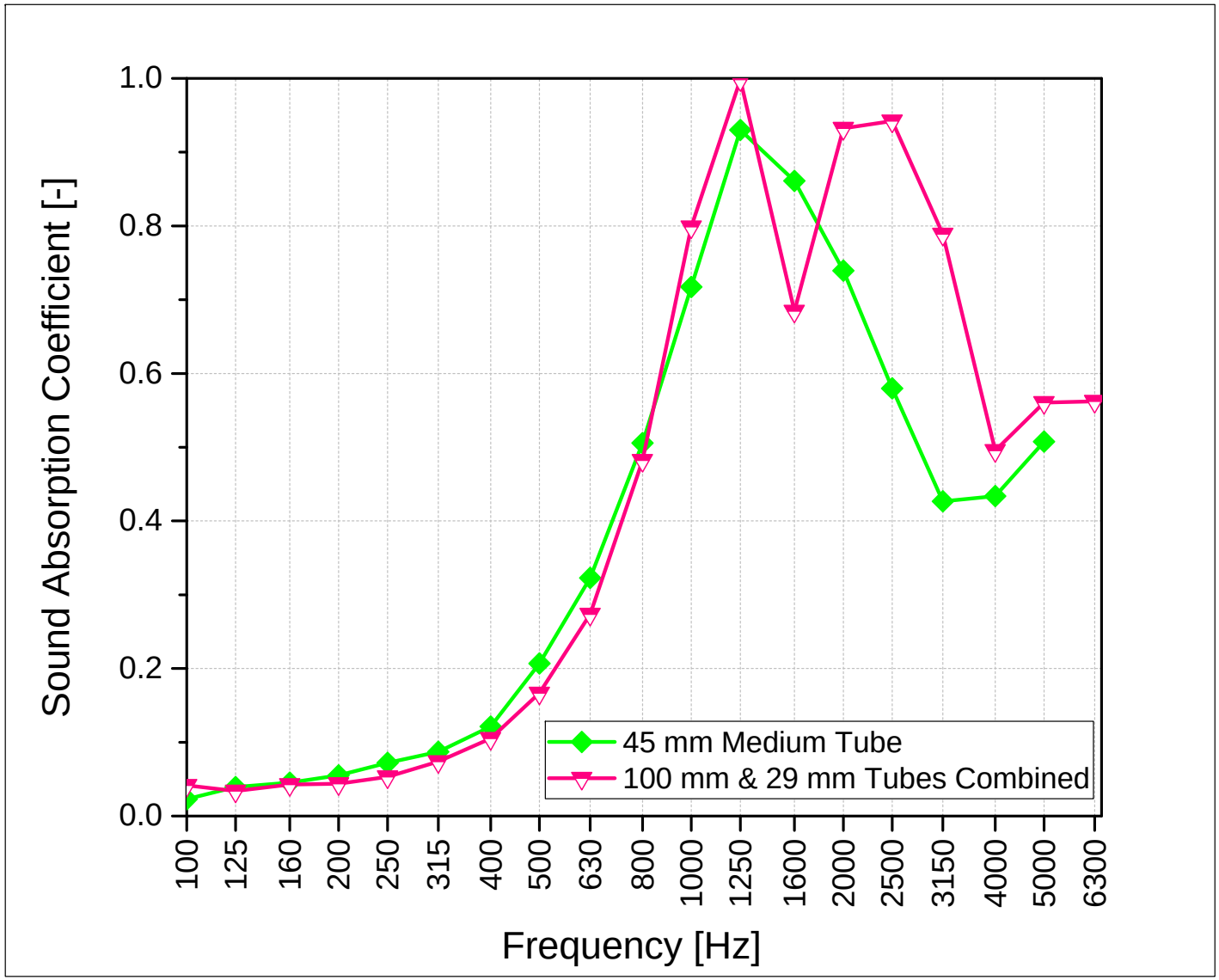


Impedance Tube – Why 45 mm Tube for Industry?



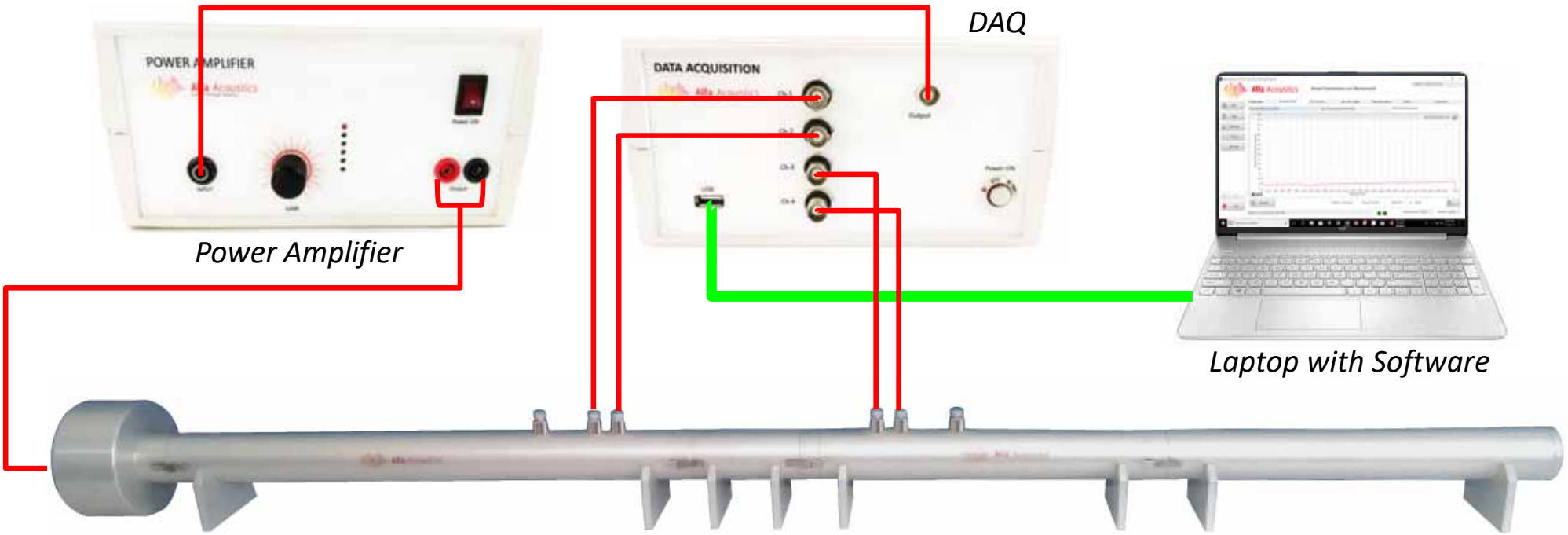
In actual all samples are not homogenous and single layer, then results from tubes will be different and it is difficult to draw any conclusion

Impedance Tube – Why 45 mm Tube for Industry?



Technically, if sample is coated with film / foil then there has to be only one resonance (45 mm tube) and not two resonances as seen in (100 mm and 29 mm tube results combined) as seen above

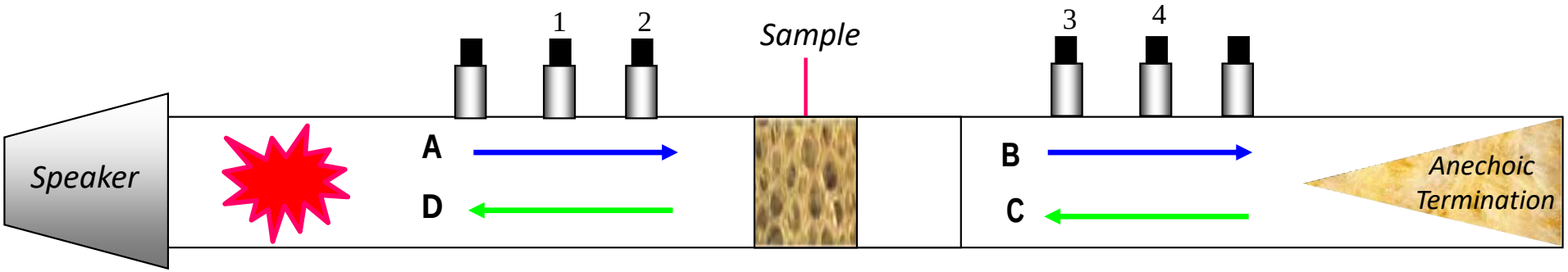
Impedance Tube – Sound Transmission Loss (STL)



Four microphone Impedance Tube

Test Samples

Impedance Tube - Transfer Matrix Approach (TMM)



$$P_1 = \left(Ae^{-jKx_1} + Be^{jKx_1} \right) e^{j\omega t} \qquad P_3 = \left(Ce^{-jKx_3} + De^{jKx_3} \right) e^{j\omega t}$$

$$P_2 = \left(Ae^{-jKx_2} + Be^{jKx_2} \right) e^{j\omega t} \qquad P_4 = \left(Ce^{-jKx_4} + De^{jKx_4} \right) e^{j\omega t}$$

By using Decomposition theory for plane waves:

$$A = \frac{j\left(P_1 e^{jKx_2} - P_2 e^{jKx_1} \right)}{2\sin K\left(x_1 - x_2 \right)} \qquad B = \frac{j\left(P_2 e^{-jKx_1} - P_1 e^{jKx_2} \right)}{2\sin K\left(x_1 - x_2 \right)}$$

$$C = \frac{j\left(P_3 e^{jKx_4} - P_4 e^{jKx_3} \right)}{2\sin K\left(x_3 - x_4 \right)} \qquad D = \frac{j\left(P_4 e^{-jKx_3} - P_3 e^{-jKx_4} \right)}{2\sin K\left(x_3 - x_4 \right)}$$

Impedance Tube - Transfer Matrix Approach (TMM)

Transfer Matrix formulation :

$$\begin{pmatrix} P \\ V \end{pmatrix}_{x=0} = \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} \begin{pmatrix} P \\ V \end{pmatrix}_{x=d}$$

$$\begin{cases} P\big|_{x=0} = A + B \\ V\big|_{x=0} = \dfrac{A-B}{\rho_0 c} \\ P\big|_{x=d} = Ce^{-jKd} + De^{jKd} \\ V\big|_{x=0} = \dfrac{Ce^{-jKd} - De^{jKd}}{\rho_0 c} \end{cases}$$

Homogeneity and Isotropy hypothesis:

$$T_{11} = T_{22} \qquad T_{11}T_{22} - T_{12}T_{21} = 1$$

Symmetry Reciprocity

It can be proved:

$$\begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} = \begin{pmatrix} \cos k_c d & j \cdot Zc \cdot \sin kd \\ \dfrac{j \sin kd}{Zc} & \cos k_c d \end{pmatrix}$$

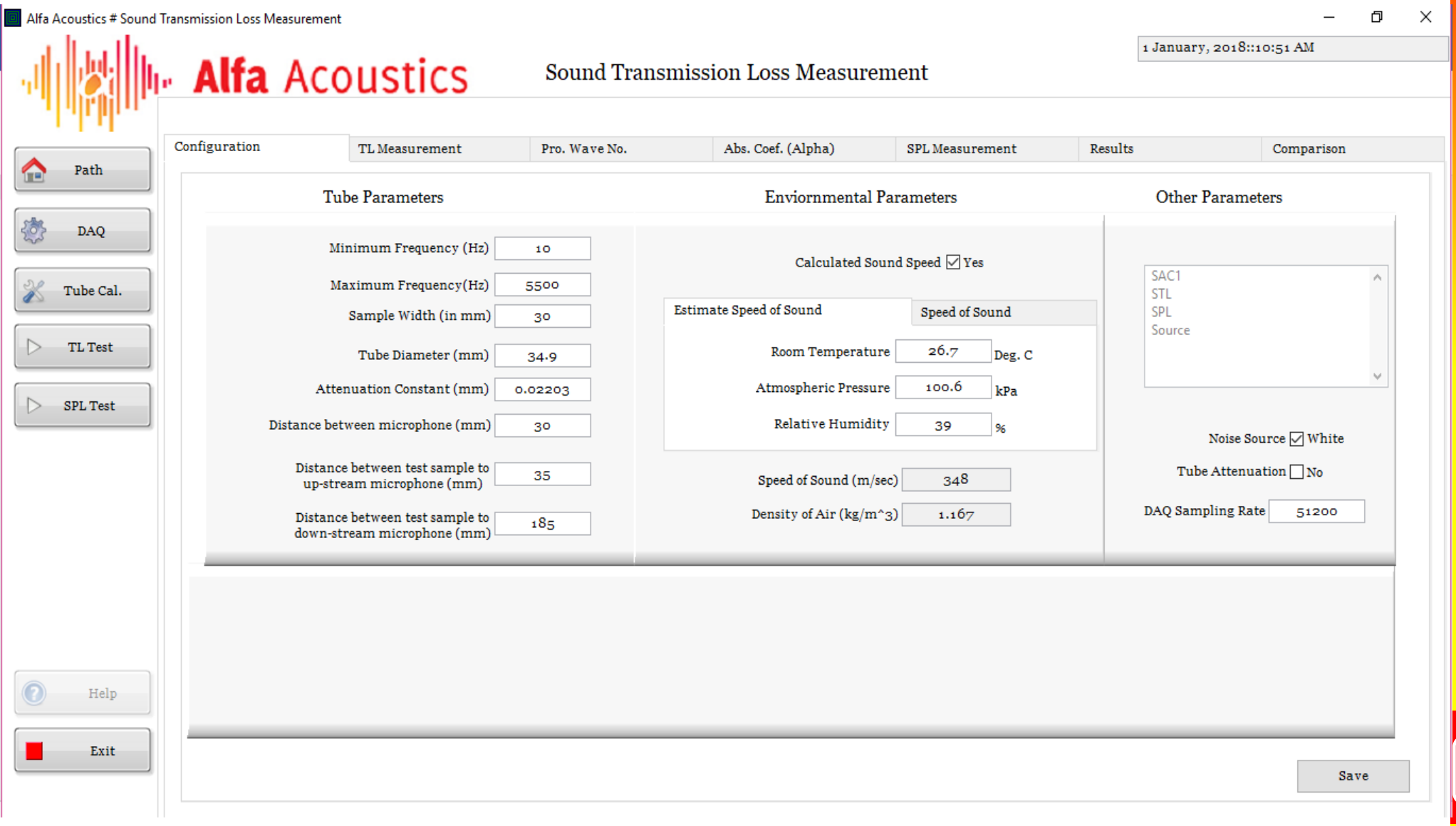
Reflection Coefficient

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

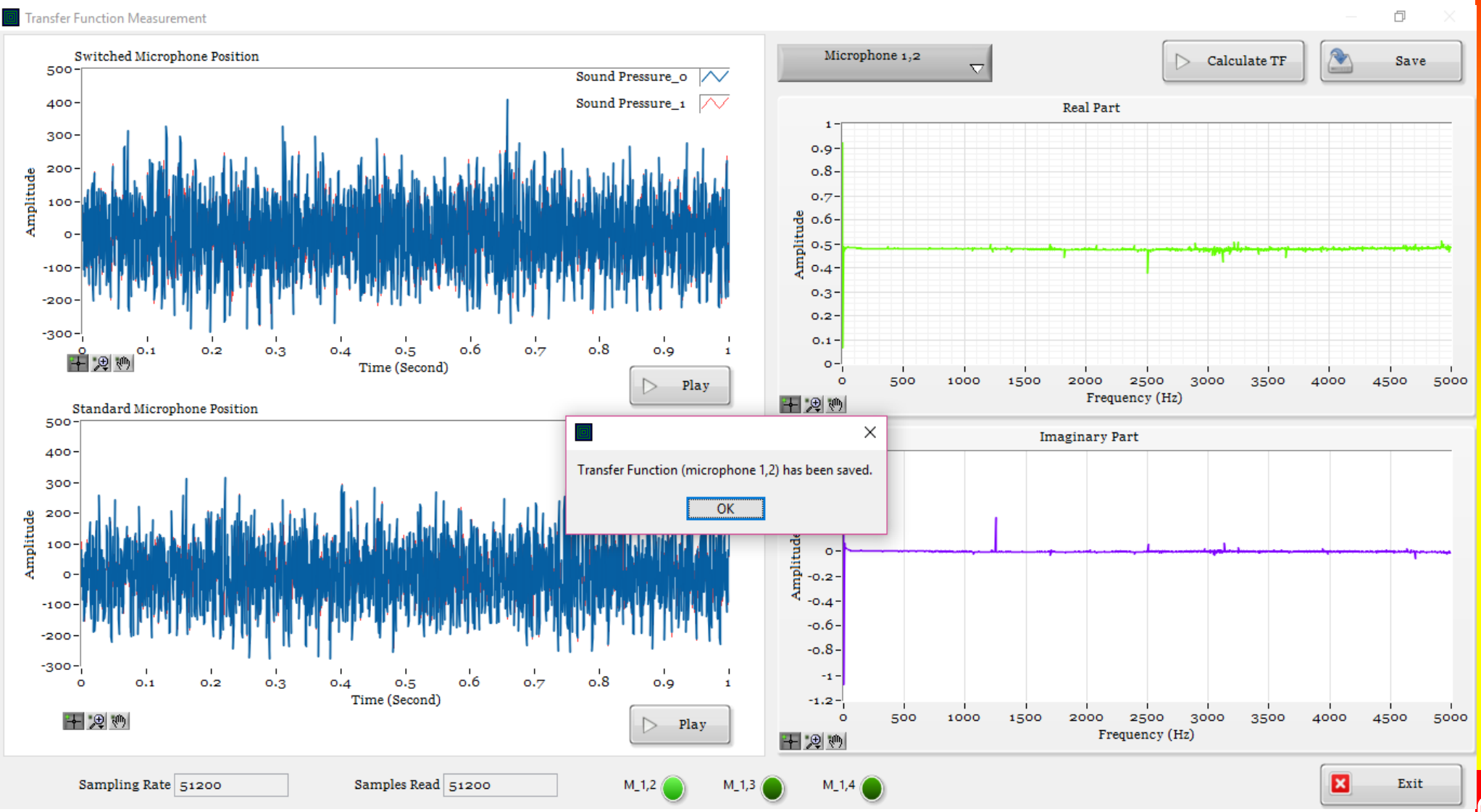
Transmission Coefficient

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

Sound Transmission Loss – Software Interface



Sound Transmission Loss – Calibration



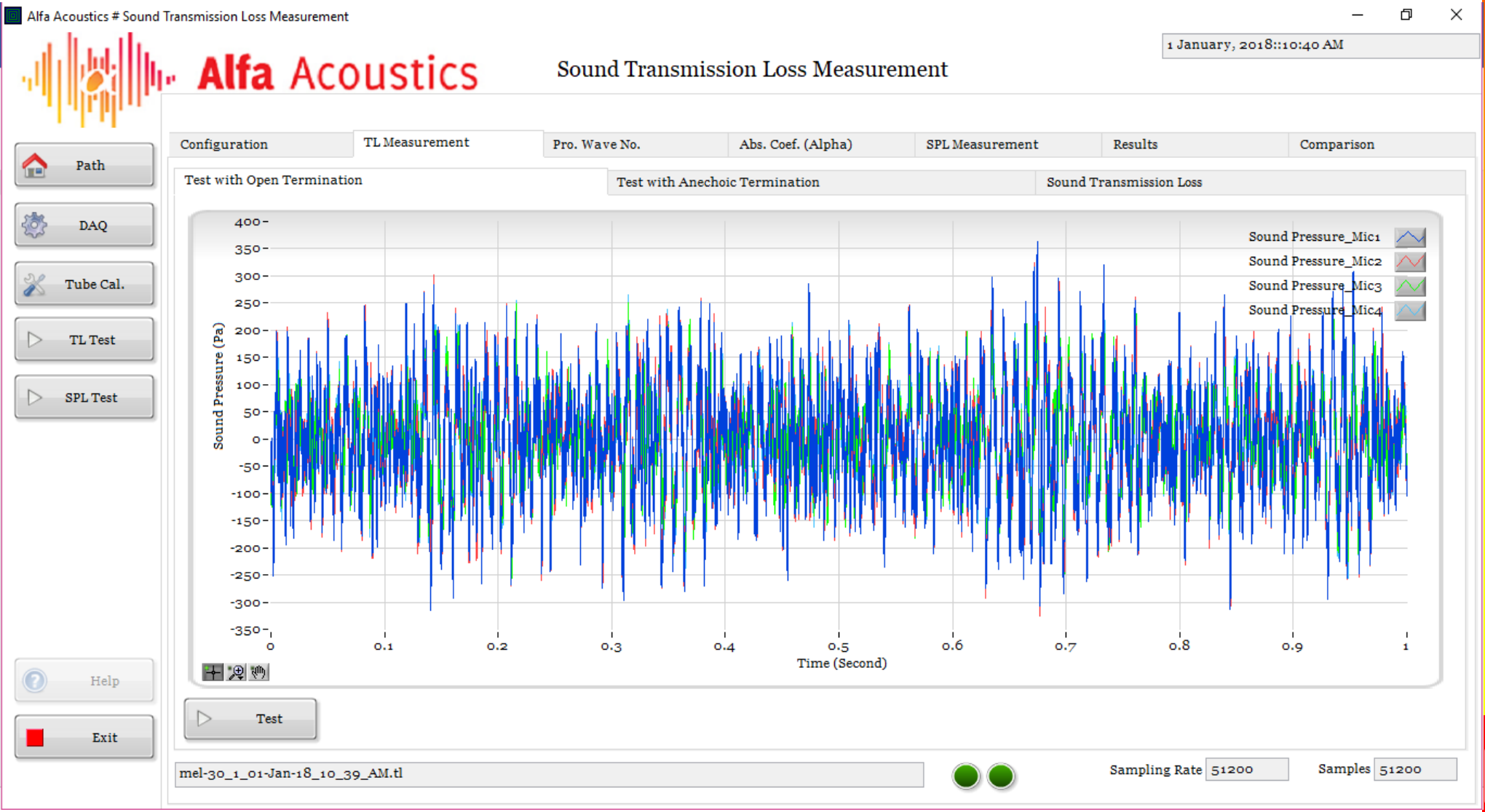
Perform –

Microphone Calibration Positions- 1 & 2

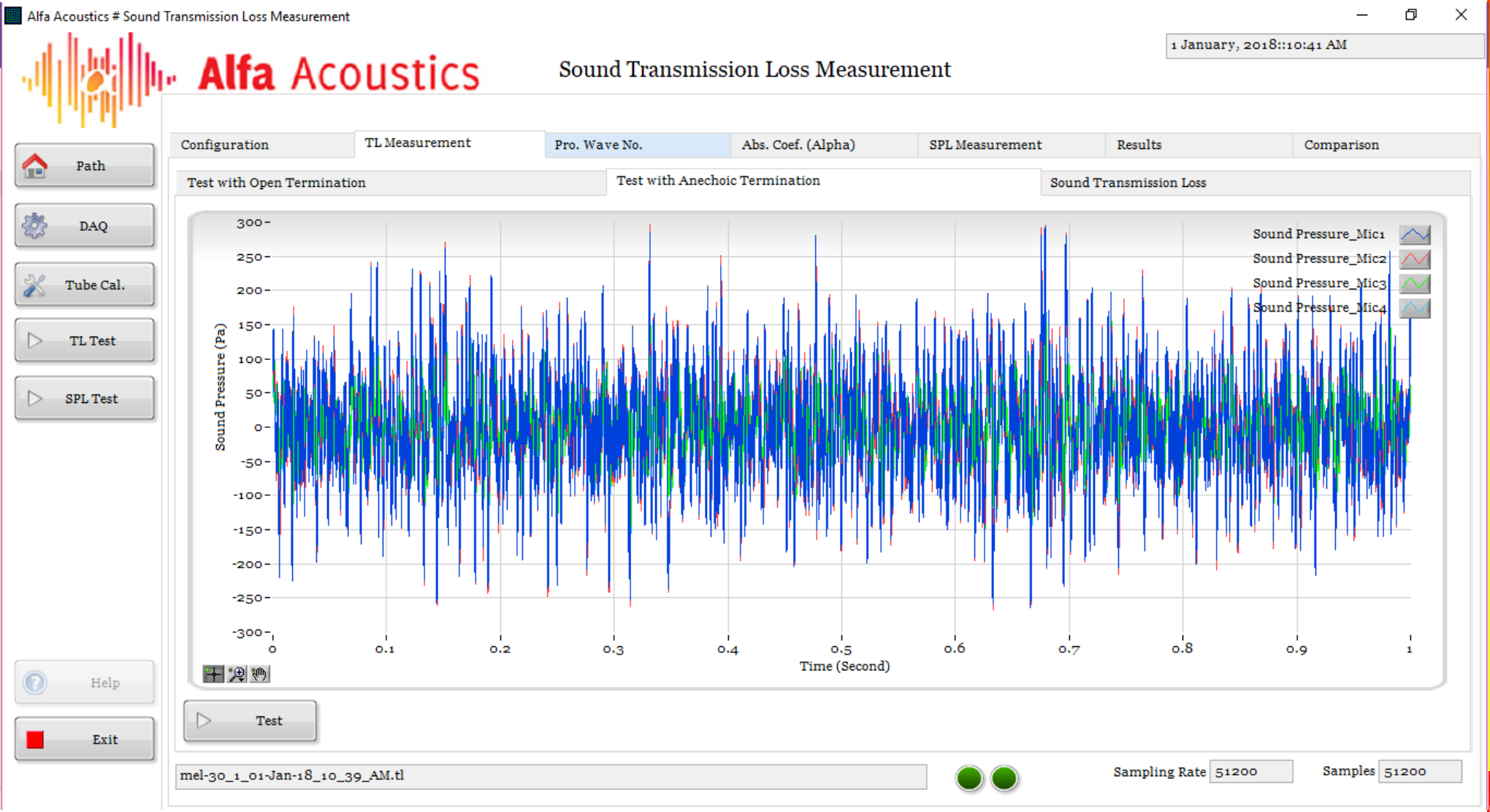
Microphone Calibration Positions- 1 & 3

Microphone Calibration Positions- 1 & 4

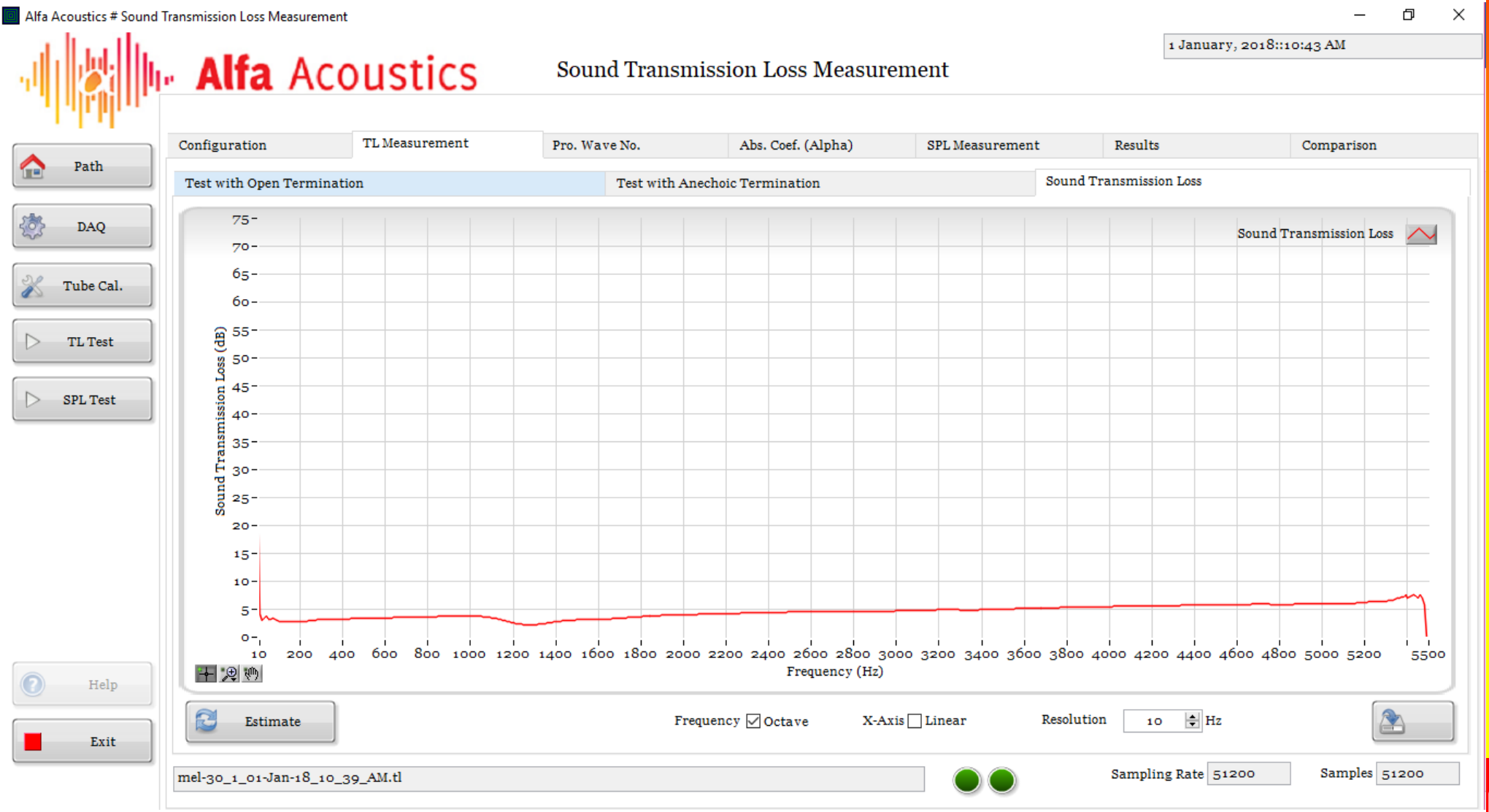
Sound Transmission Loss – Open Termination Measurement



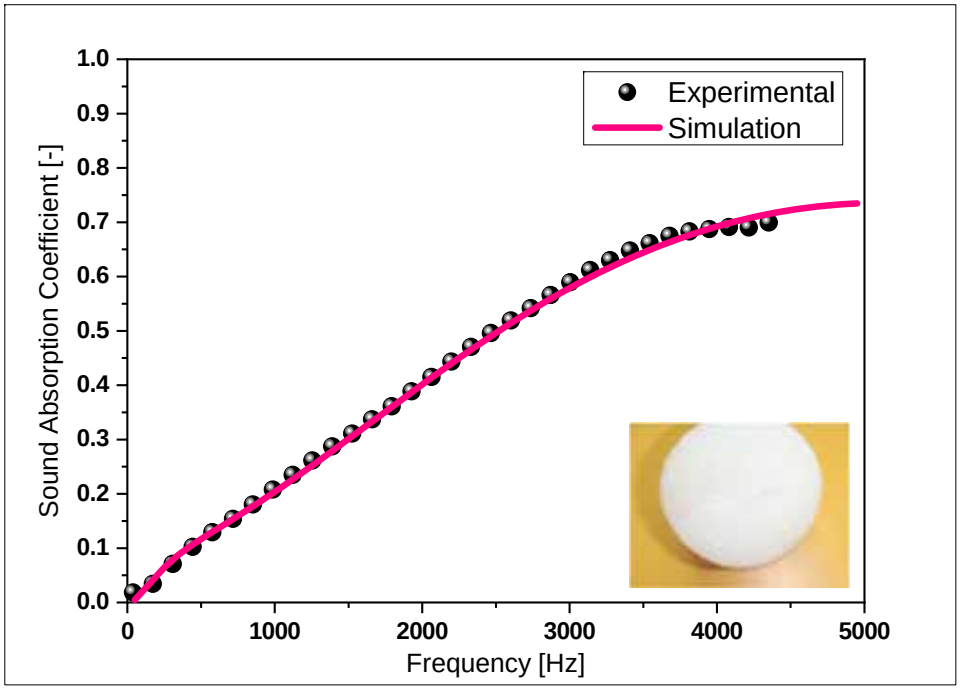
Sound Transmission Loss – Closed Termination Measurement

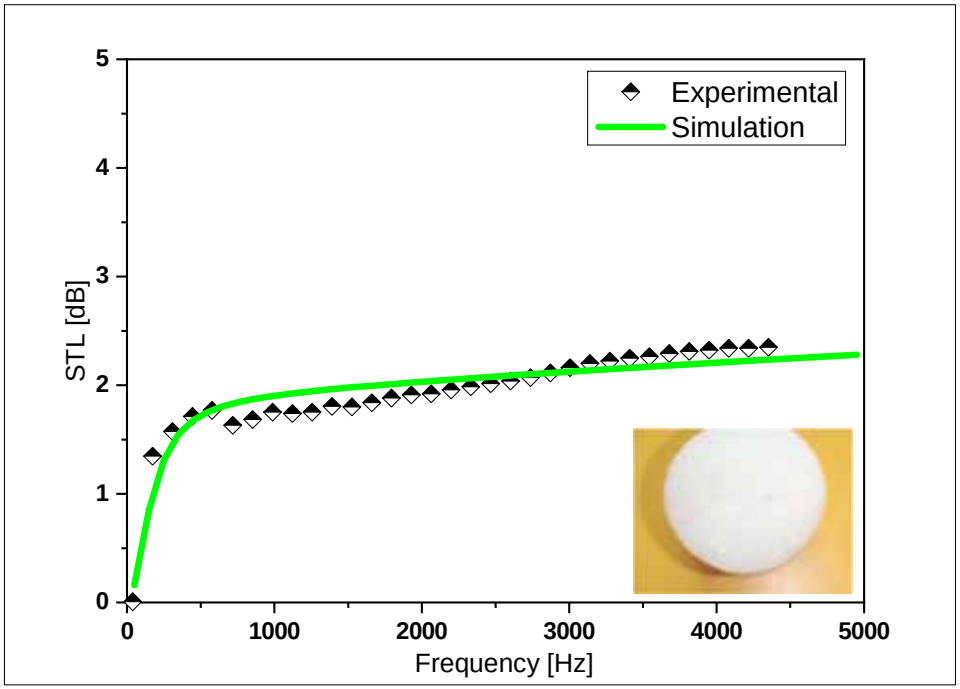


Sound Transmission Loss – Estimation

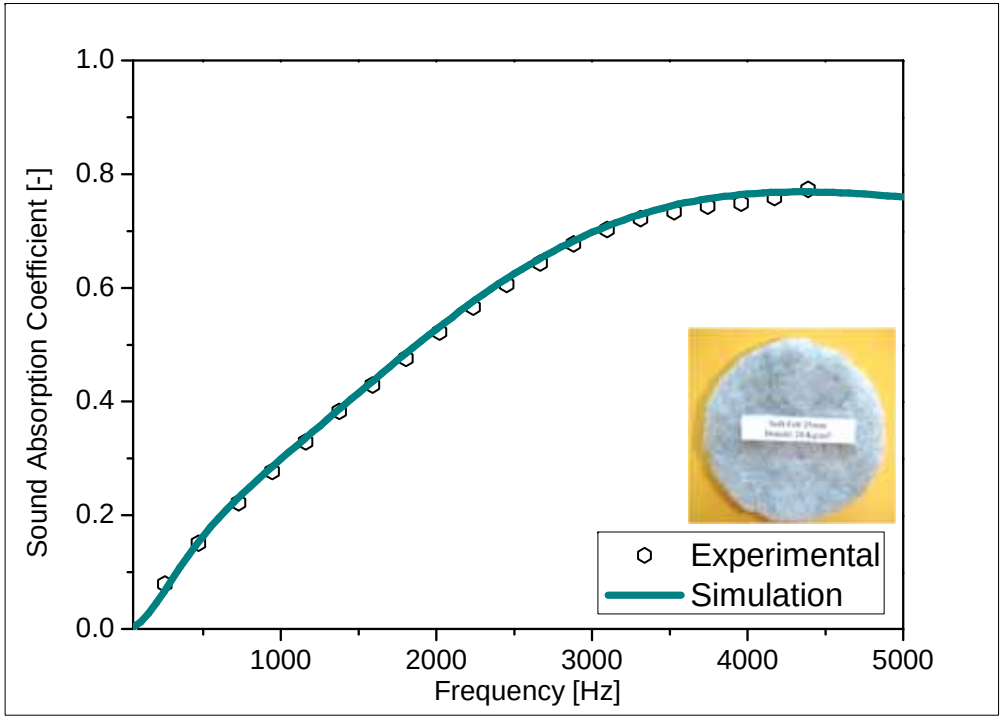


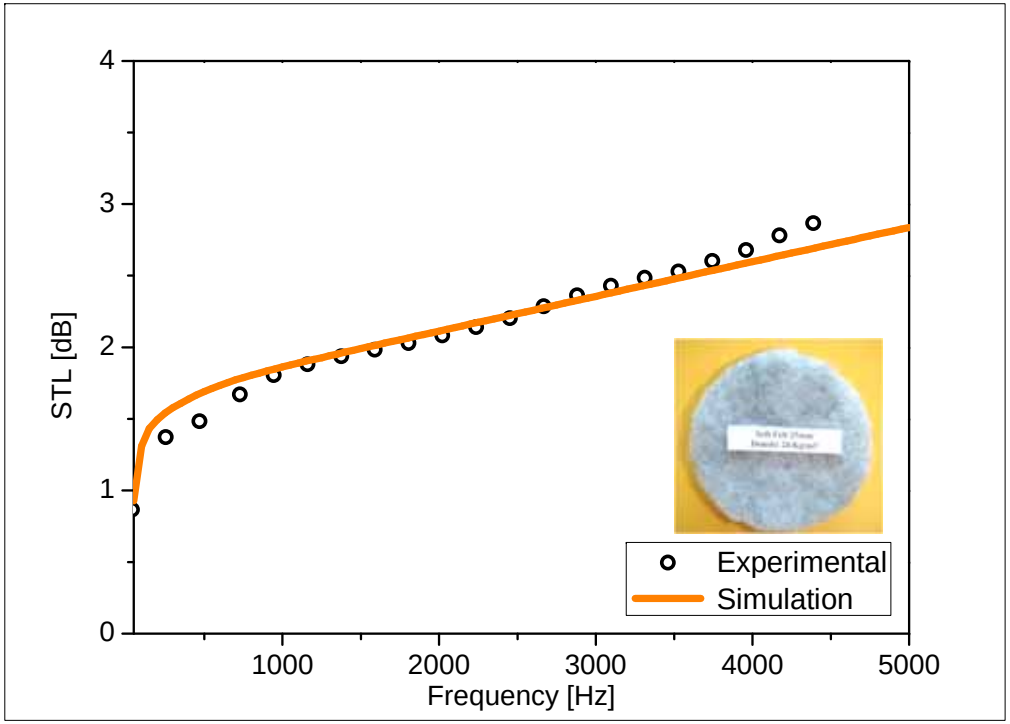
Test Results - Polyster Fiber 20mm-30kg/m^3





Test Results - Soft Felt 25 mm-24kg/m^3

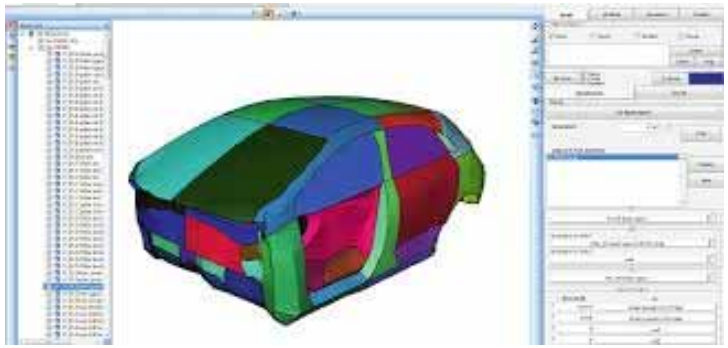


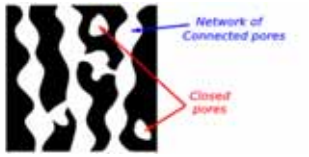


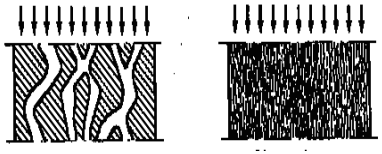
Impedance Tube – Why 45 mm Tube for Industry?

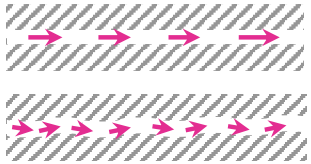
Vehicle Level Simulation – Five Intrinsic Physical Parameters by Inversion (Biot Parameters)

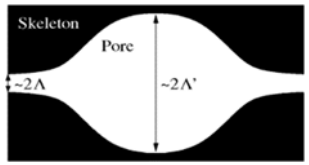
- **Porosity**
- **Air-flow resistivity**
- **Tortuosity**
- **Viscous Characteristic Length**
- **Thermal Characteristic Length**











Comparison of Different Models:

Models	Ultra-low Cost	Low Cost	Advanced - Industry
Diameter	45/35 mm	45/35 mm	45/35 mm
Frequency Range	100-5000 Hz	100-5000 Hz	100-5000 Hz
Test Standards	ASTM E1050	ASTM E1050	ISO 10534-2 / ASTM E1050
DAQ	Alfa Acoustics Make- 4 IN 1 OT	Alfa Acoustics Make- 4 IN 1 OT	Alfa Acoustics Make- 4 IN 1 OT, 3 OT in Spare
Microphones	Isemtech – ¼”	GRAS Free field– ¼”	GRAS Pressure field– ¼”
Software	1 PC	Multiple PC Lifetime	Multiple PC Lifetime
Dummy Holders for fast testing	-	2 nos	2 nos
AMC	Chargeable	2 Vists Free in 2nd Year	2nd Year AMC Free
Additional Accessories	-	-	Yes, for different types of samples
Spare TL Tube	-	-	Dummy tube for boundary condition

Thank you for being with us. 

Alfa Acoustics
Silence through Science
An ISO 9001: 2015 Company

Dr. Paresh Shravage
Technical Head

+91 9423208575 / +91 9975082075
alfa@alfaacoustics.com
alfaacoustics@gmail.com
www.alfaacoustics.com

Plot No.5, Swami Vivekanad Soc. Walhekar Wadi Rd,
Chinchwad, Pune - 411033, India