



# Acoustic Material Testing - Impedance Tube and Standards

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**Alfa Acoustics**  
Silence through Science

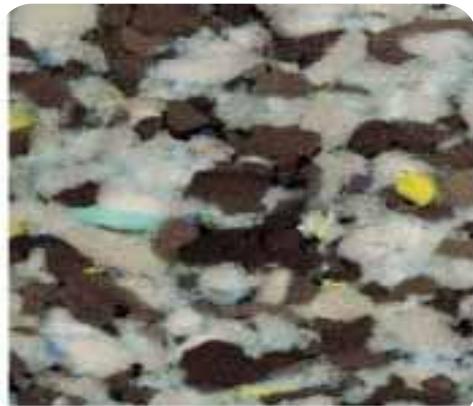
An ISO 9001:2015 Company

# Outline -

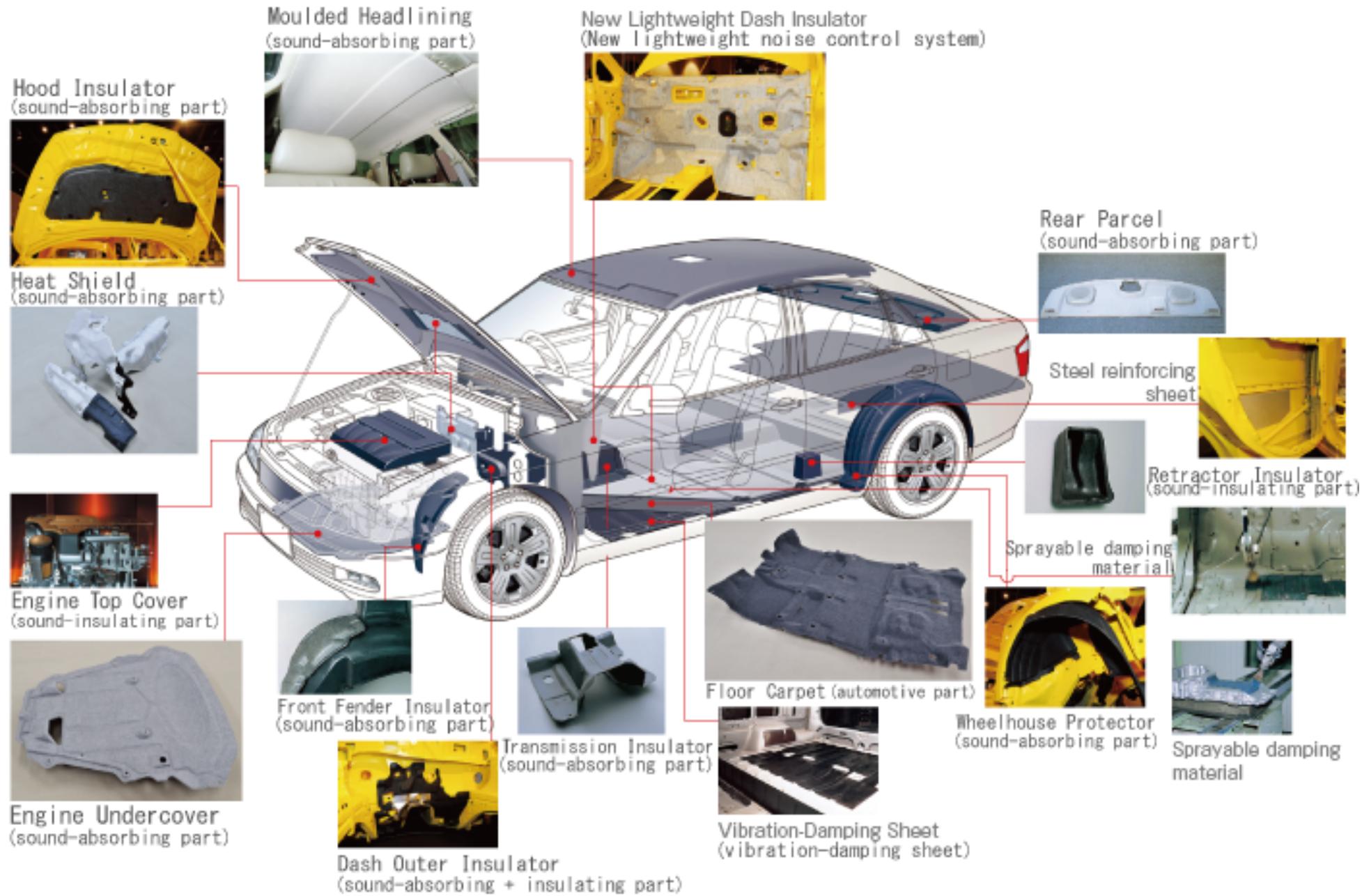
- Acoustic materials, types
- Acoustic material applications-Automotive and Architectural
- Sound absorption coefficient
- Sound transmission loss
- Testing methods
- Sample preparation
- Test standards
- Impedance tube Testing

# Acoustic Materials -

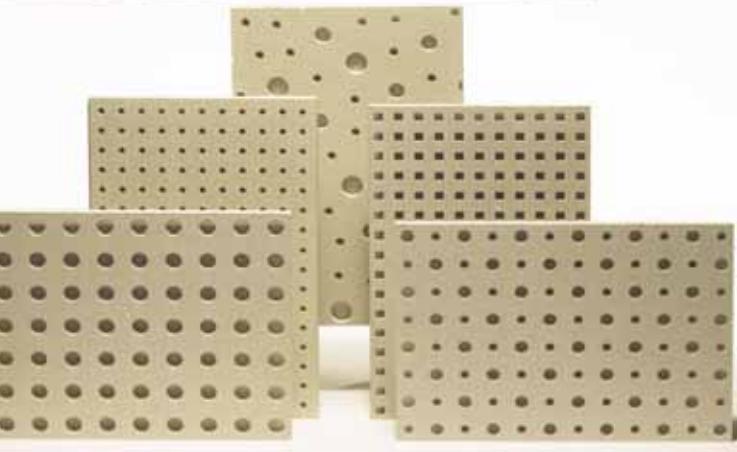
- Porous Foams - e.g. Melamine, Polyurethane
- Fibrous Materials- e.g. Glass Wool, Fiberform
- Felts (Recycled Materials)- e.g. Nonwovens, PET Felts
- Perforated and Microperforated materials



# Acoustic Material Applications-Automotive



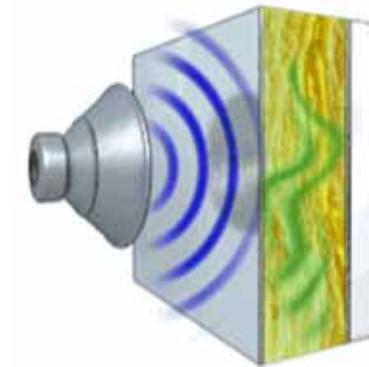
# Acoustic Material Applications-Architectural



# 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.

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



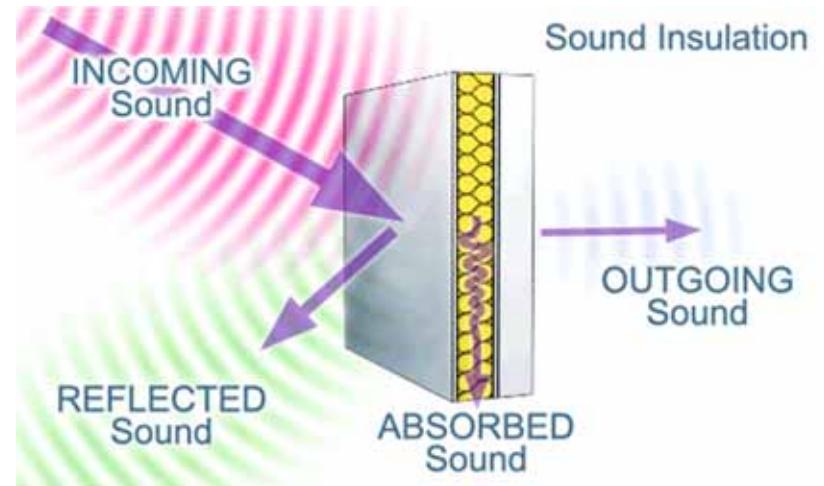
- Normal incidence sound absorption coefficient-Two Microphone Tube
- Random incidence sound absorption coefficient-Reverberation Suite

# Sound Transmission Loss -

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

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

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



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

# Test Standards -

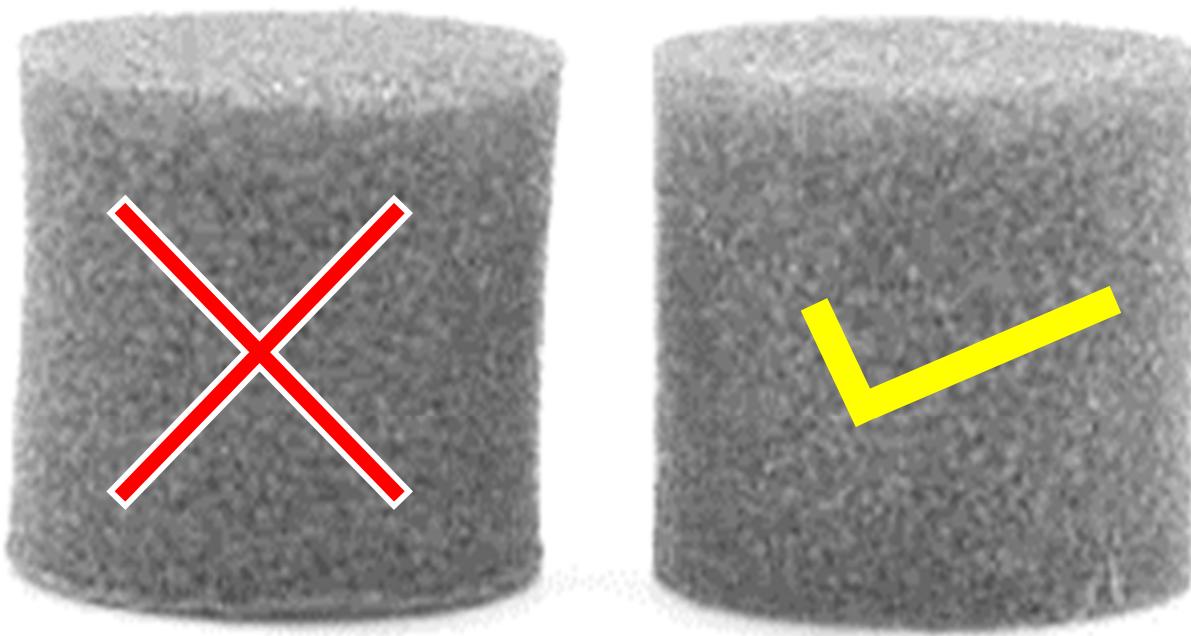
- **Two-microphone Impedance Tube Method**
  - ISO 10534-2: 1998- Acoustics - Determination of sound absorption coefficient and impedance in impedance tubes - Part 2: Transfer function method
  - ASTM E1050:2019- Standard Test Method for Impedance and Absorption of Acoustical Materials Using A Tube, 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”



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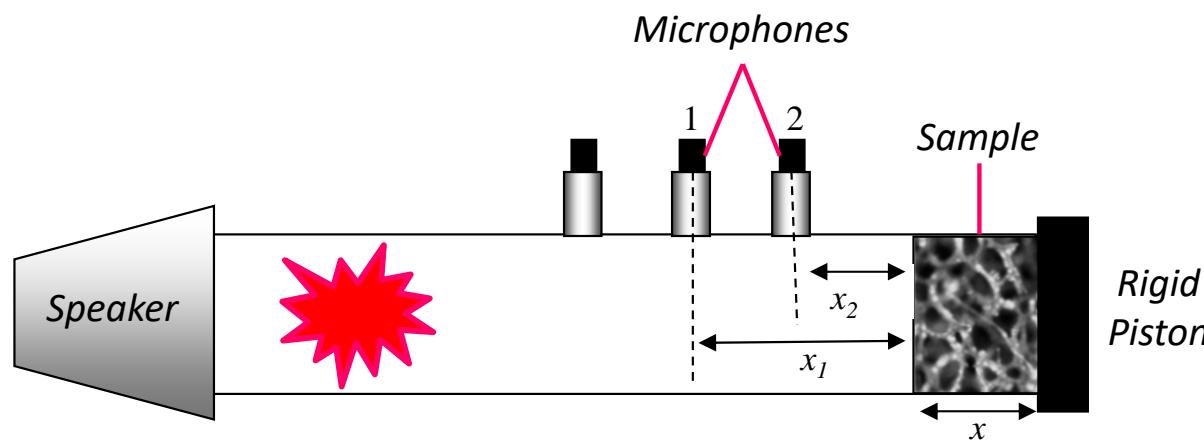
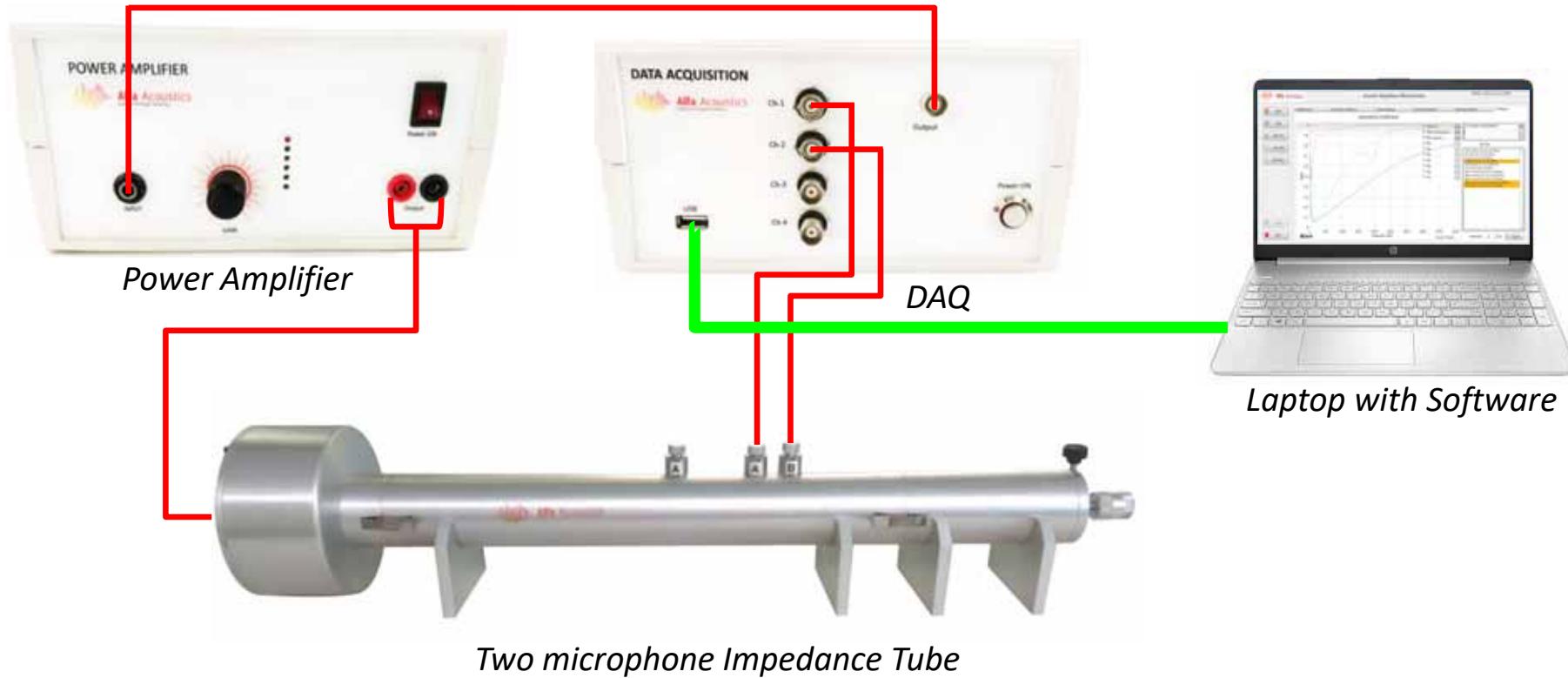
[10]

# 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	$\frac{1}{4}$ ", Pressure Field – 4 Nos			
Loudspeaker	4" in diameter, 15 Watts, 6 Ohm			



# Impedance Tube – Sound Absorption Coefficient



*Test Samples*

# Impedance Tube –Plane Wave Theory

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

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

The transfer function for the incident wave alone  $H_I$  is:

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

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  $H_{12}$  for the total sound field may now be obtained by

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

# Impedance Tube –Plane Wave Theory

Solving for  $R$ :

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

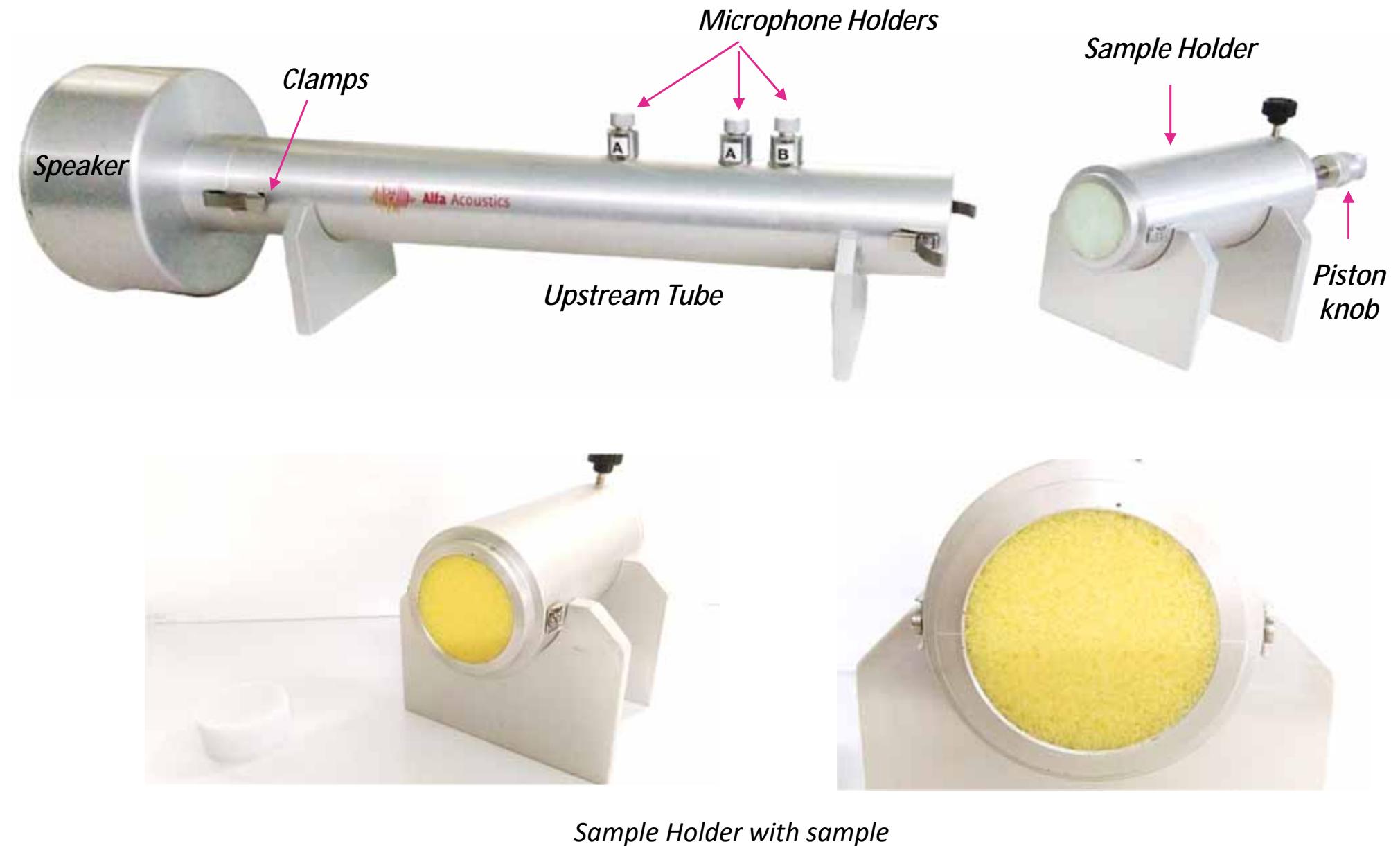
Sound absorption coefficient ( $\alpha$ )

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

Normalized specific boundary impedance:

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

# Sound Absorption Measurement -



# Sound Absorption –Software Interface

Alfa Acoustics # Sound Absorption Measurement

1 January, 2018::10:53 AM

## Alfa Acoustics

Silence through Science

### Sound Absorption Measurement

Configuration Sound Absorption Raw Data Impedance Reflection SPL Measurement Results Compare

Path DAQ Tube Cal. Imp. Test SPL Meas. Help Exit Save

Environmental Parameters

Calculated Sound Speed  Yes

Estimate Speed of Sound  Speed of Sound

Room Temperature 26.3 Deg. C

Atmospheric Pressure 100.6 kPa

Relative Humidity 39 %

Speed of Sound (m/sec) 347.75

Density of Air (kg/m<sup>3</sup>) 1.168

Tube Parameters

Minimum Frequency (Hz) 10

Maximum Frequency(Hz) 5000

Distance between microphones (in mm) 30

Distance between test sample to nearest microphone (in mm) 35

Tube Diameter (mm) 34.9

Attenuation Constant (mm) 343

Tube Attenuation  No

Other Parameters

SAC1  
STL  
SPL  
Source

Noise Source  White Noise

Sampling Rate 51200

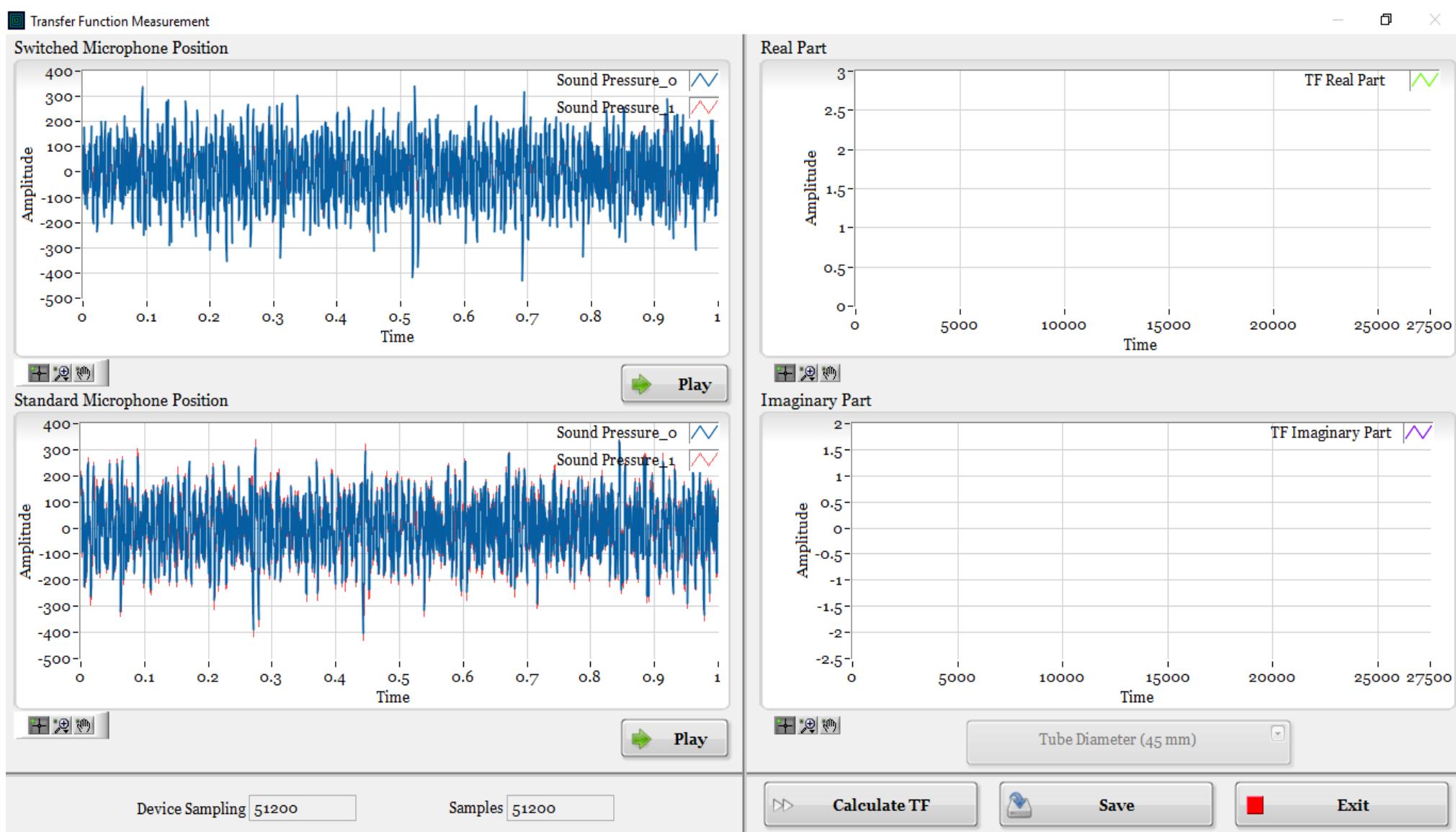
Window Length 5

New Filter  Yes

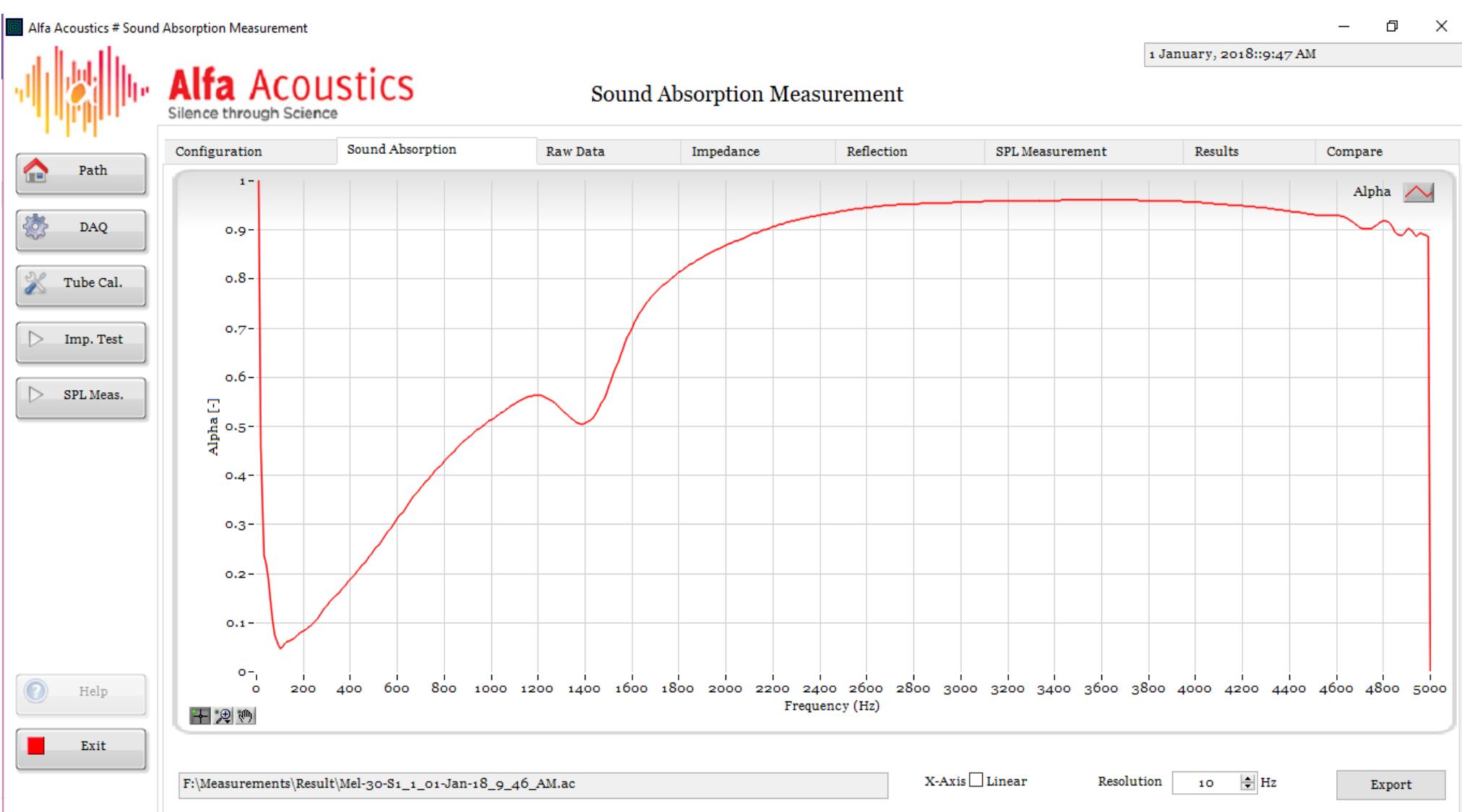
[16]

The screenshot shows the Alfa Acoustics Sound Absorption Measurement software interface. The main window title is "Alfa Acoustics # Sound Absorption Measurement" and the date/time is "1 January, 2018::10:53 AM". The interface includes a logo for "Alfa Acoustics Silence through Science" and a navigation bar with tabs: Configuration, Sound Absorption, Raw Data, Impedance, Reflection, SPL Measurement, Results, and Compare. On the left, there is a vertical toolbar with icons for Path, DAQ, Tube Cal., Imp. Test, SPL Meas., Help, and Exit. The main content area is titled "Sound Absorption Measurement" and contains three main sections: Environmental Parameters, Tube Parameters, and Other Parameters. The Environmental Parameters section includes fields for Room Temperature (26.3), Atmospheric Pressure (100.6), Relative Humidity (39%), Speed of Sound (347.75), and Density of Air (1.168). The Tube Parameters section includes fields for Minimum Frequency (10 Hz), Maximum Frequency (5000 Hz), Distance between microphones (30 mm), Distance between test sample to nearest microphone (35 mm), Tube Diameter (34.9 mm), Attenuation Constant (343 mm), and Tube Attenuation (checkbox). The Other Parameters section includes a dropdown menu for "SAC1" containing "STL", "SPL", and "Source", and several checkboxes for noise source (White Noise), sampling rate (51200), window length (5), and new filter (Yes).

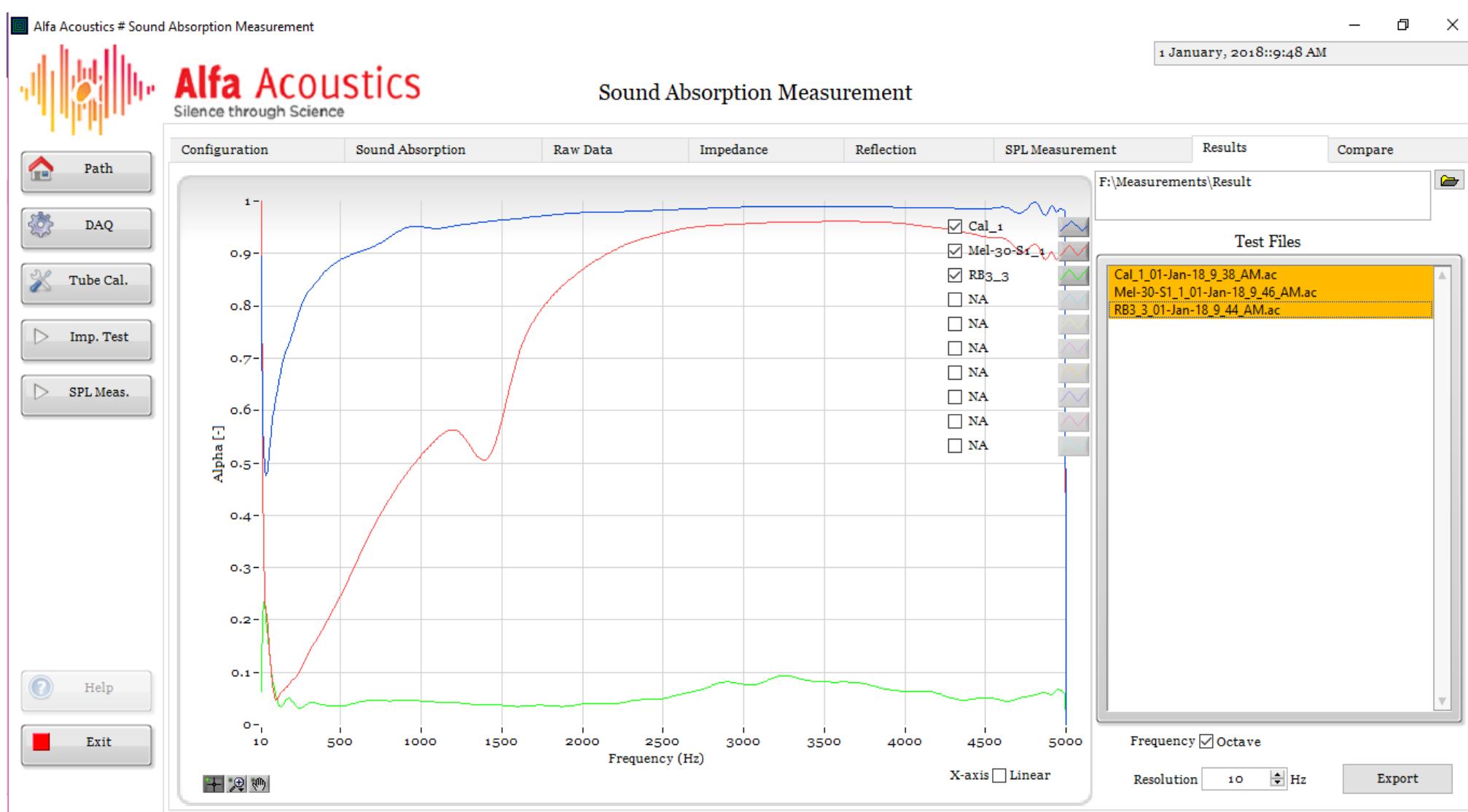
# Sound Absorption Software – Calibration



# Sound Absorption Software – Measurement



# Sound Absorption Software – Result Export

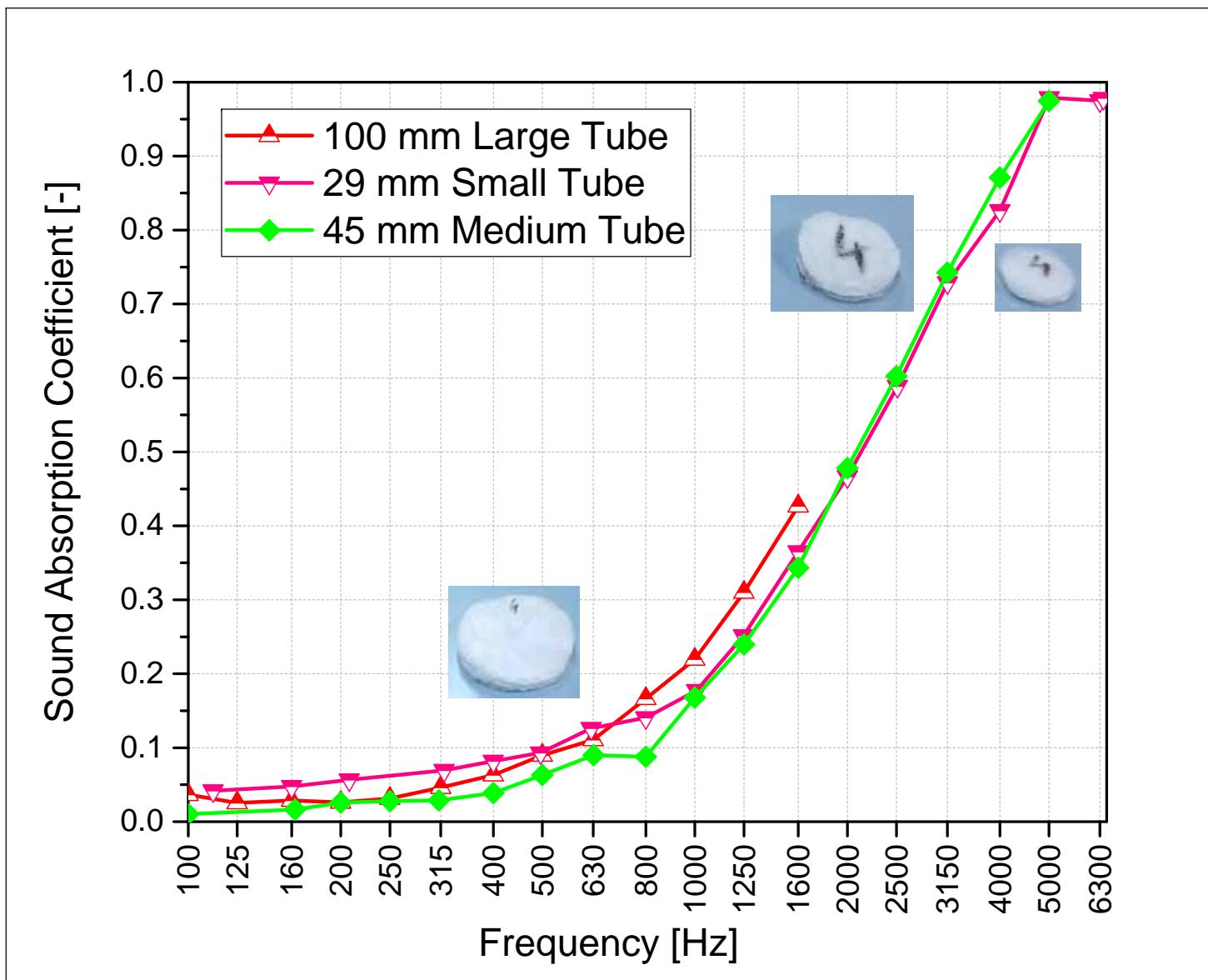


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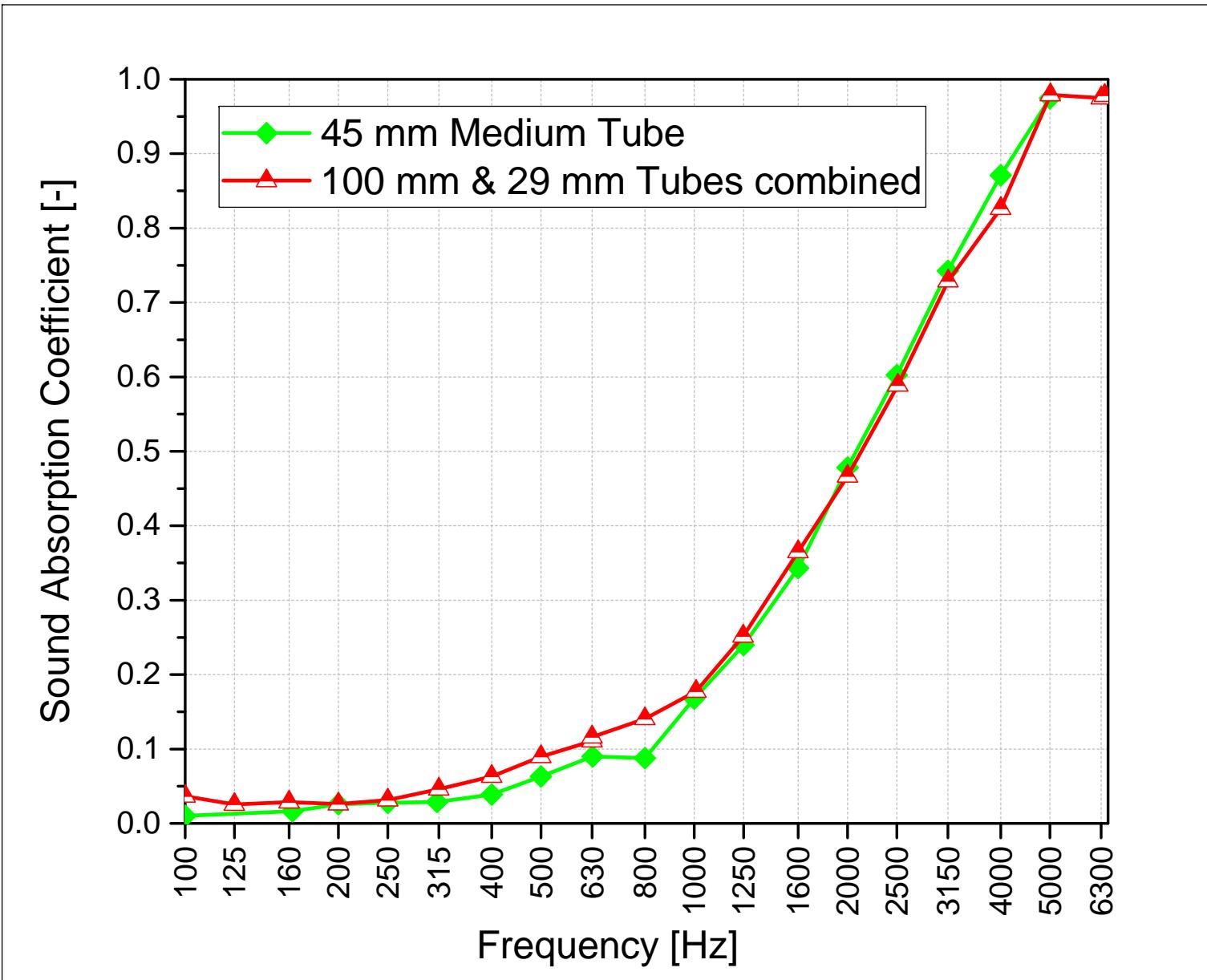
[19]

# Impedance Tube – Why 45 mm Tube for Industry?

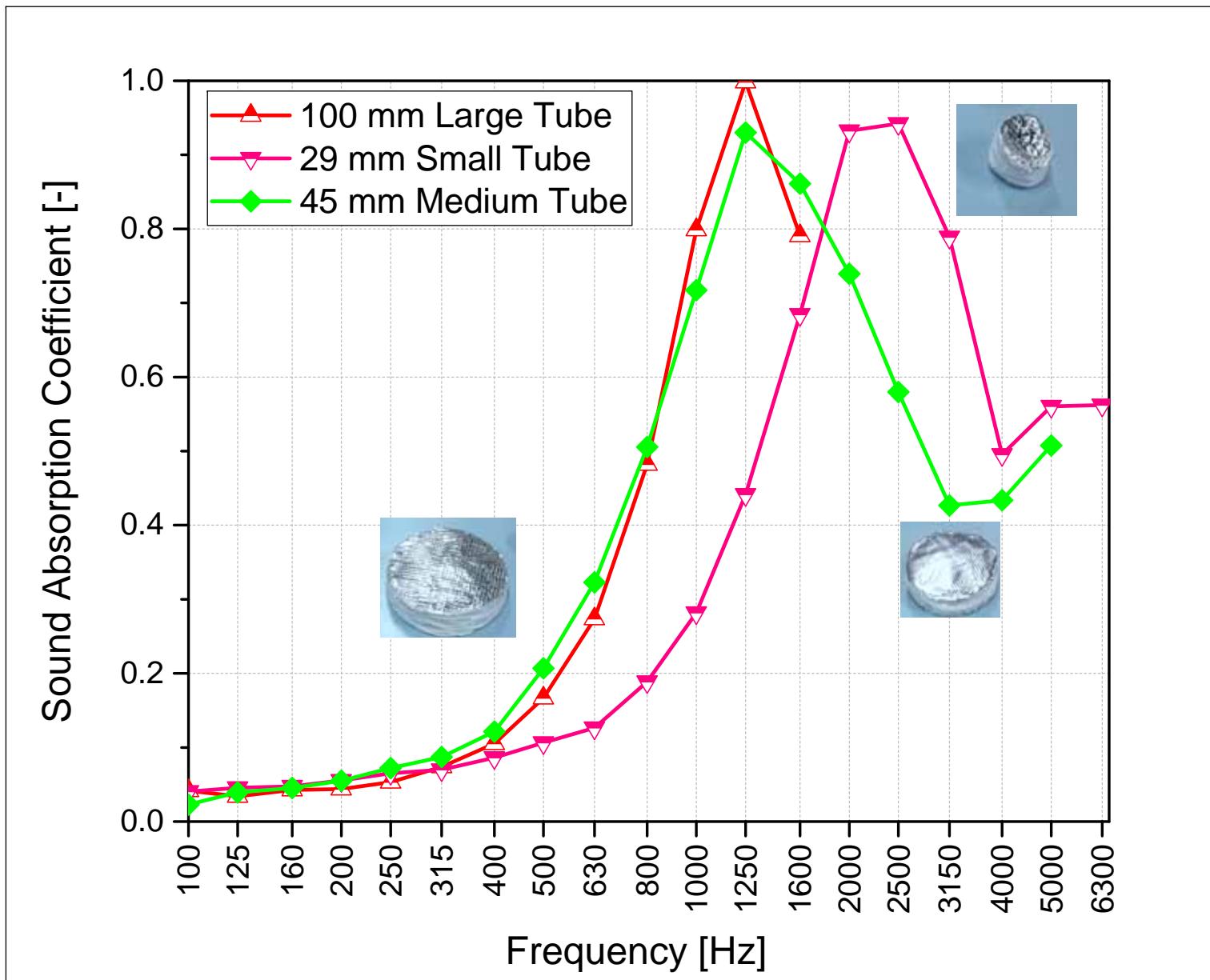


If sample is homogenous and single layer, then results from tubes will be similar

# Impedance Tube – Why 45 mm Tube for Industry?

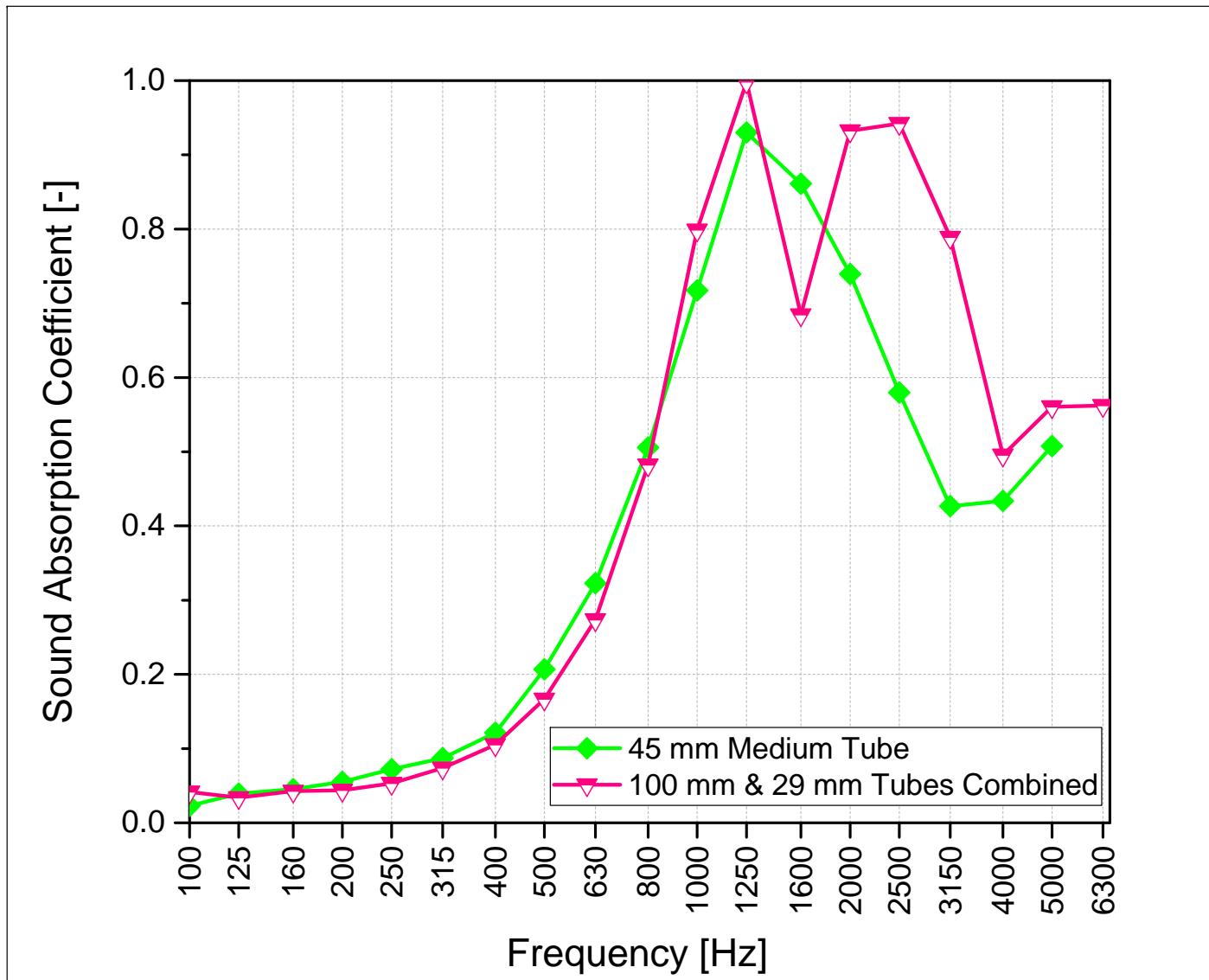


# Impedance Tube – Why 45 mm Tube for Industry?



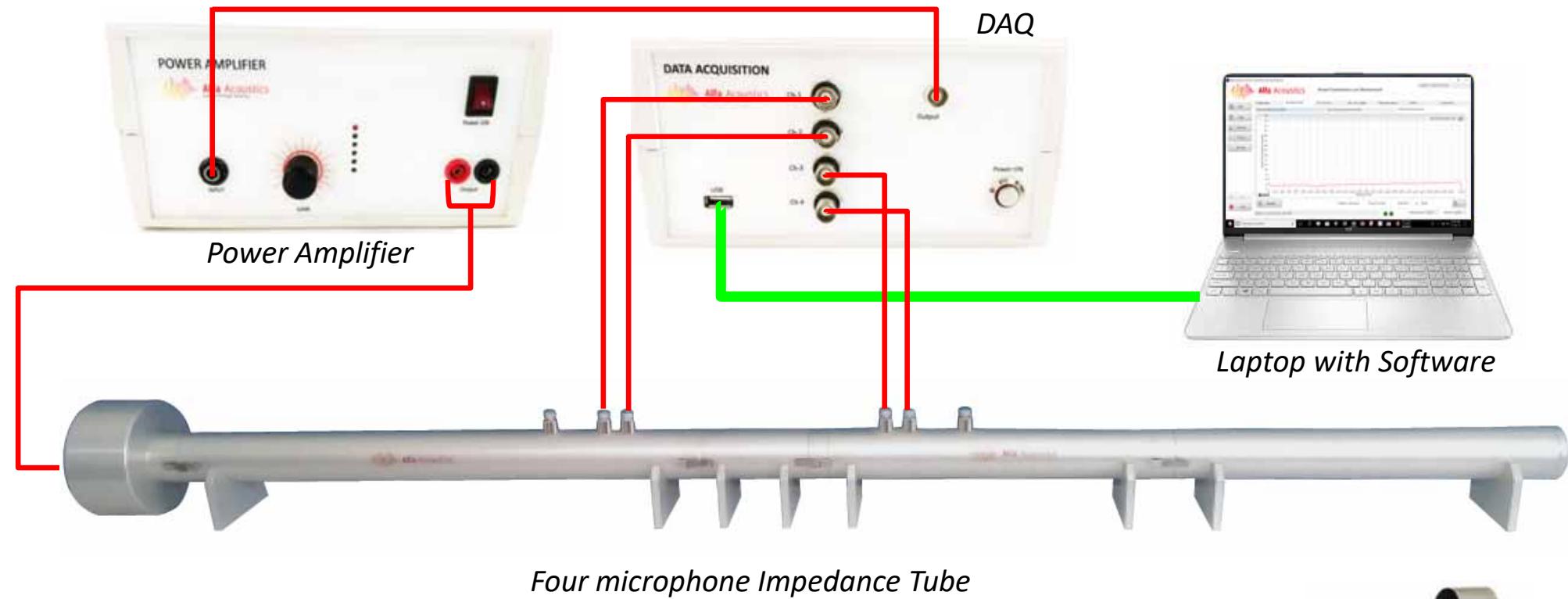
*In actual all samples are not homogenous and single layer, then results from tubes will be different and it is difficult to draw any conclusion*

# Impedance Tube – Why 45 mm Tube for Industry?

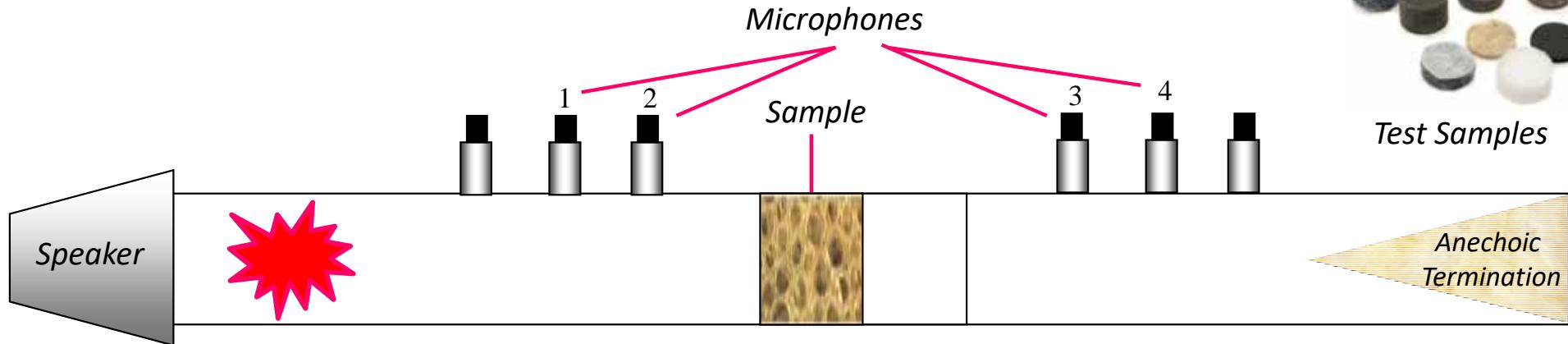


Technically, if sample is coated with film / foil then there has to be only one resonance (45 mm tube) and not two resonances as seen in (100 mm and 29 mm tube results combined) as seen above

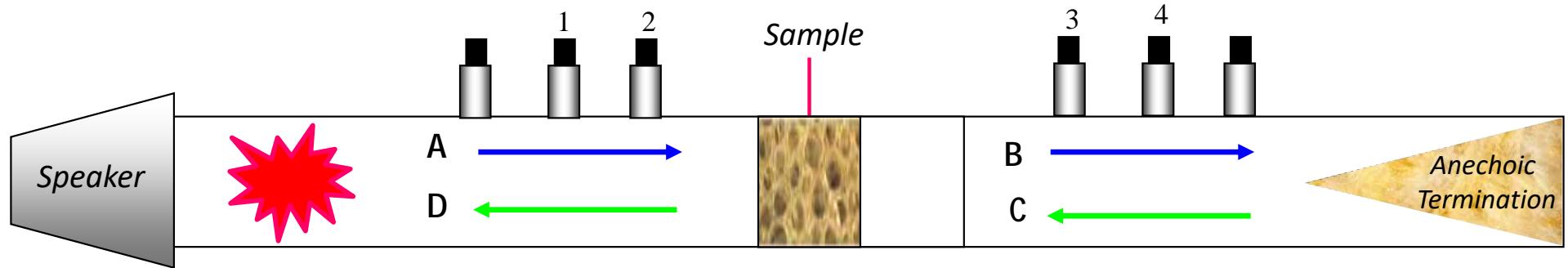
# Impedance Tube – Sound Transmission Loss (STL)



*Four microphone Impedance Tube*



# Impedance Tube - Transfer Matrix Approach (TMM)



$$P_1 = (Ae^{-jKx_1} + Be^{jKx_1})e^{j\omega t}$$

$$P_3 = (Ce^{-jKx_3} + De^{jKx_3})e^{j\omega t}$$

$$P_2 = (Ae^{-jKx_2} + Be^{jKx_2})e^{j\omega t}$$

$$P_4 = (Ce^{-jKx_4} + De^{jKx_4})e^{j\omega t}$$

By using Decomposition theory for plane waves:

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

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

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

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

# Impedance Tube - Transfer Matrix Approach (TMM)

Transfer Matrix formulation :

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

Homogeneity and Isotropy hypothesis:

$$T_{11} = T_{22}$$

Symmetry

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

Reciprocity

It can be proved:

$$\begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} = \begin{pmatrix} \cos k_c d & j \cdot Z_c \cdot \sin k d \\ \frac{j \sin k d}{Z_c} & \cos k_c d \end{pmatrix}$$

Reflection Coefficient

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

Transmission Coefficient

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

# Sound Transmission Loss – Software Interface

Alfa Acoustics # Sound Transmission Loss Measurement

1 January, 2018::10:51 AM

## Alfa Acoustics Sound Transmission Loss Measurement

Configuration    TL Measurement    Pro. Wave No.    Abs. Coef. (Alpha)    SPL Measurement    Results    Comparison

**Tube Parameters**

Minimum Frequency (Hz)	10
Maximum Frequency(Hz)	5500
Sample Width (in mm)	30
Tube Diameter (mm)	34.9
Attenuation Constant (mm)	0.02203
Distance between microphone (mm)	30
Distance between test sample to up-stream microphone (mm)	35
Distance between test sample to down-stream microphone (mm)	185

**Environmental Parameters**

Calculated Sound Speed  Yes

Estimate Speed of Sound	Speed of Sound
Room Temperature	26.7 Deg. C
Atmospheric Pressure	100.6 kPa
Relative Humidity	39 %
Speed of Sound (m/sec)	348
Density of Air (kg/m <sup>3</sup> )	1.167

**Other Parameters**

SAC1  
STL  
SPL  
Source

Noise Source  White

Tube Attenuation  No

DAQ Sampling Rate 51200

Help

Save

Exit

Path

DAQ

Tube Cal.

TL Test

SPL Test

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[27]

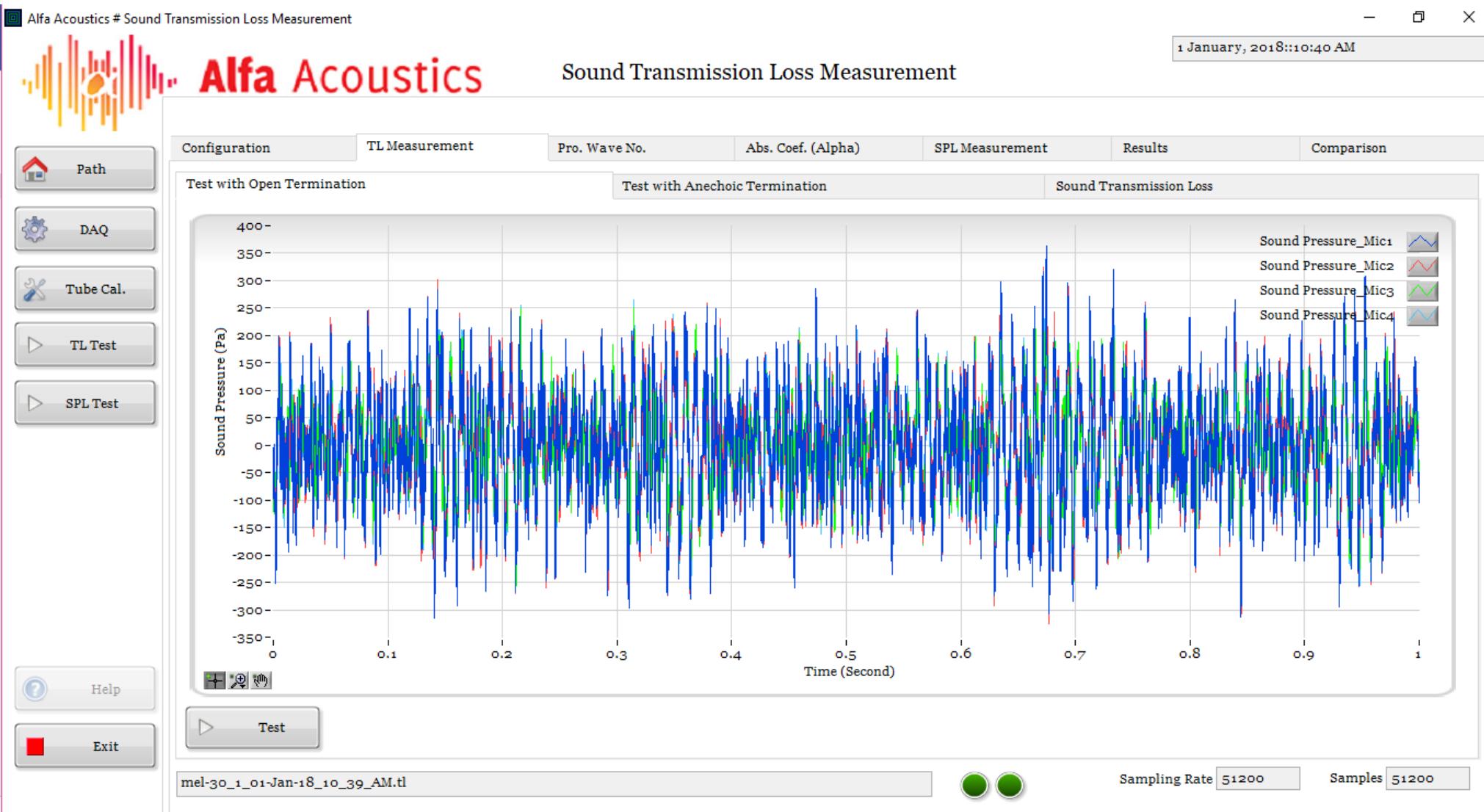
# Sound Transmission Loss – Calibration



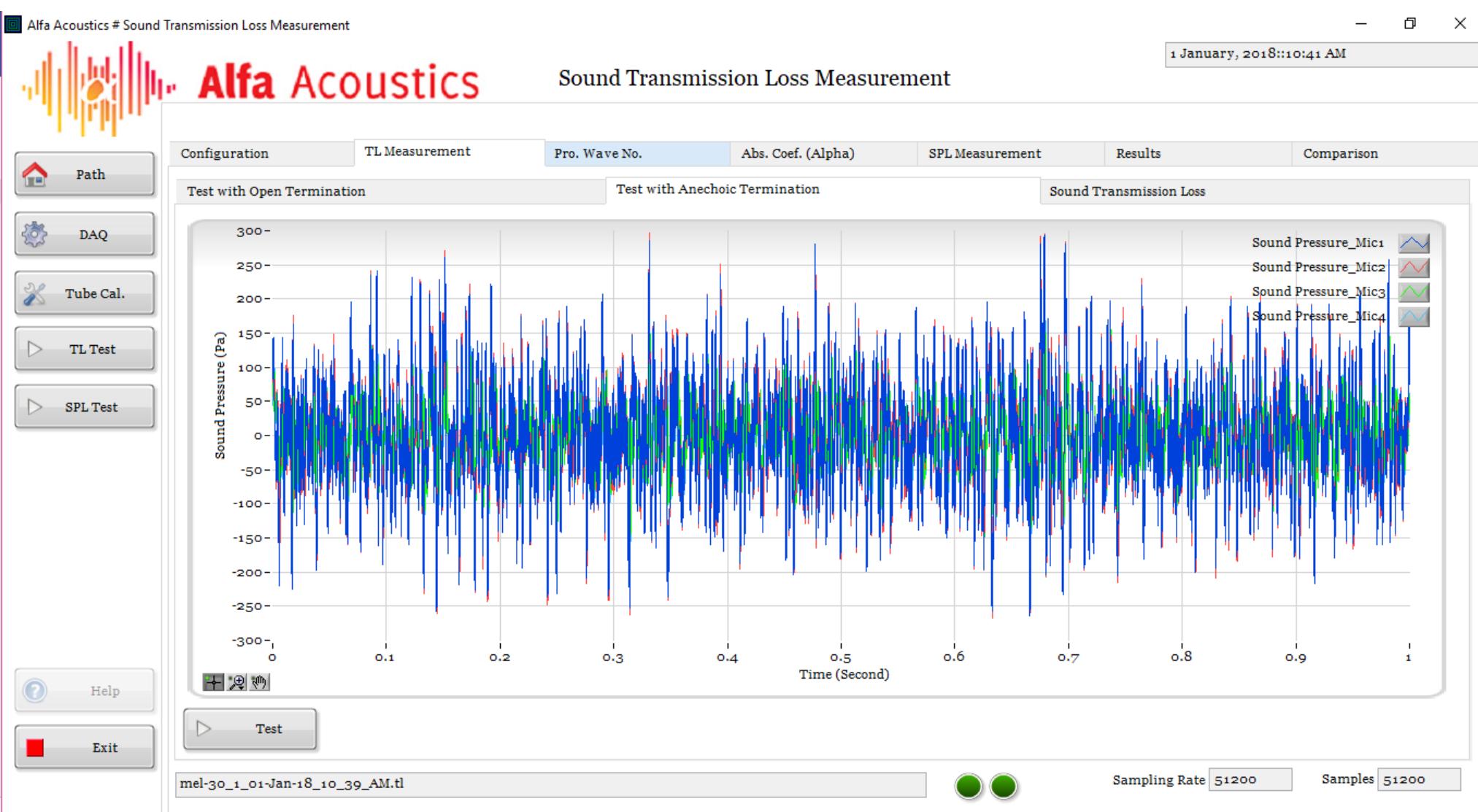
## Perform -

- Microphone Calibration Positions- 1 & 2
- Microphone Calibration Positions- 1 & 3
- Microphone Calibration Positions- 1 & 4

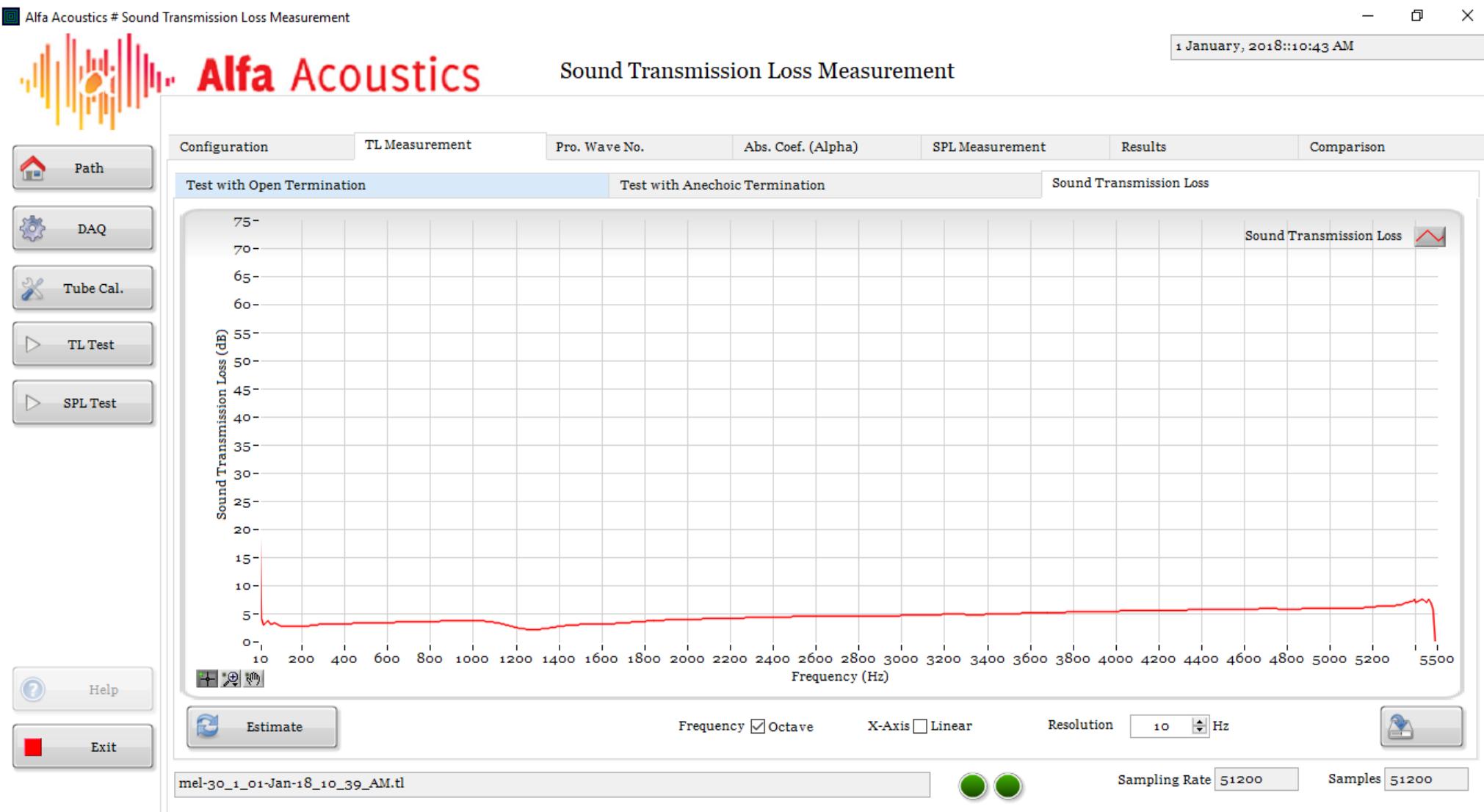
# Sound Transmission Loss – Open Termination Measurement



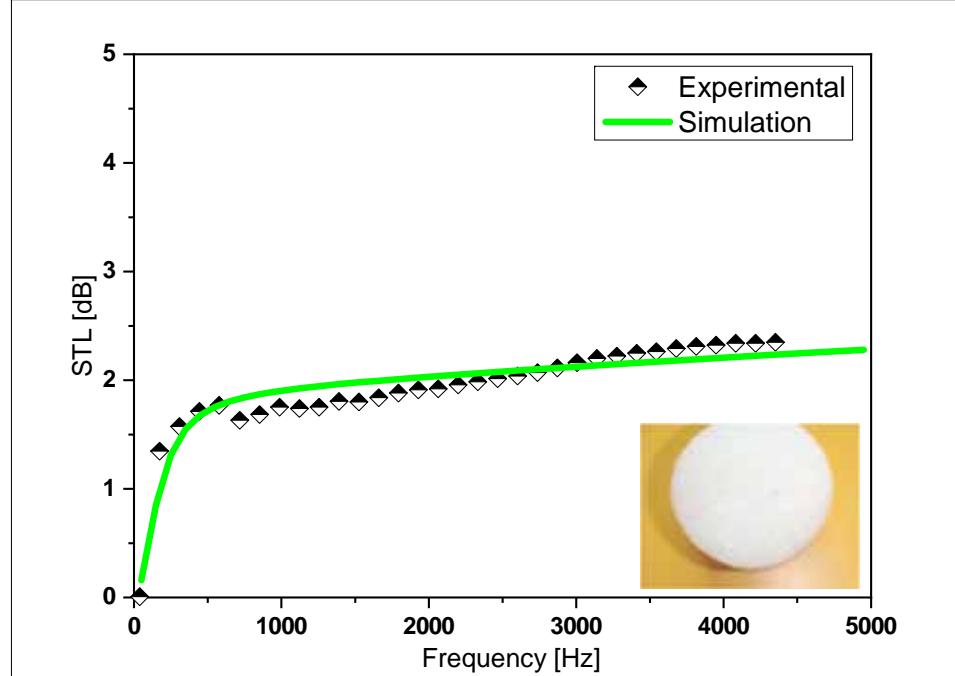
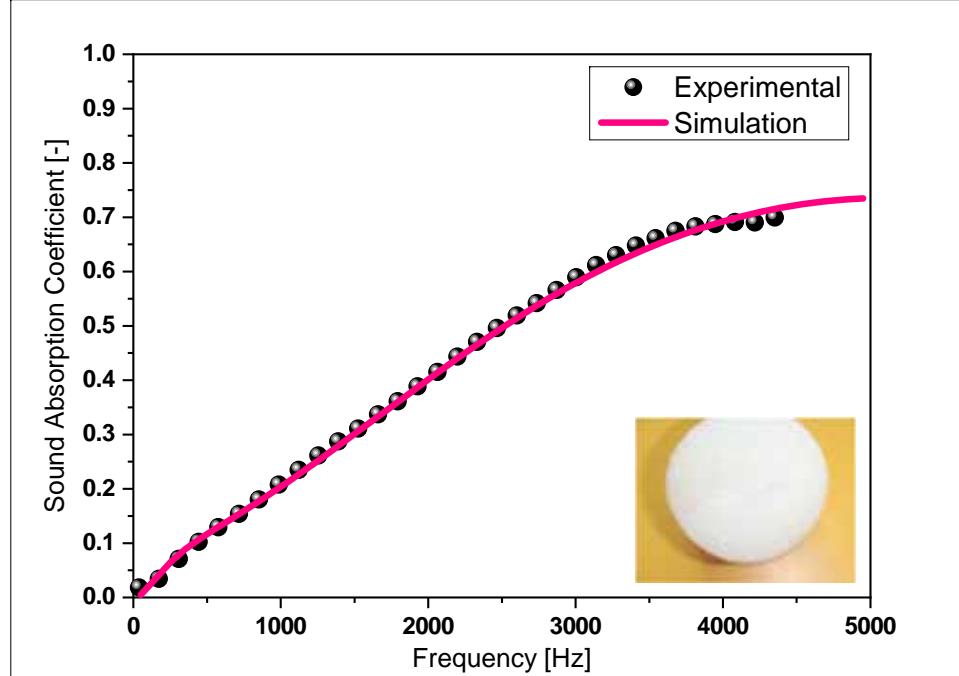
# Sound Transmission Loss – Closed Termination Measurement



# Sound Transmission Loss – Estimation



# Test Results - Polyester Fiber 20mm-30kg/m<sup>3</sup>

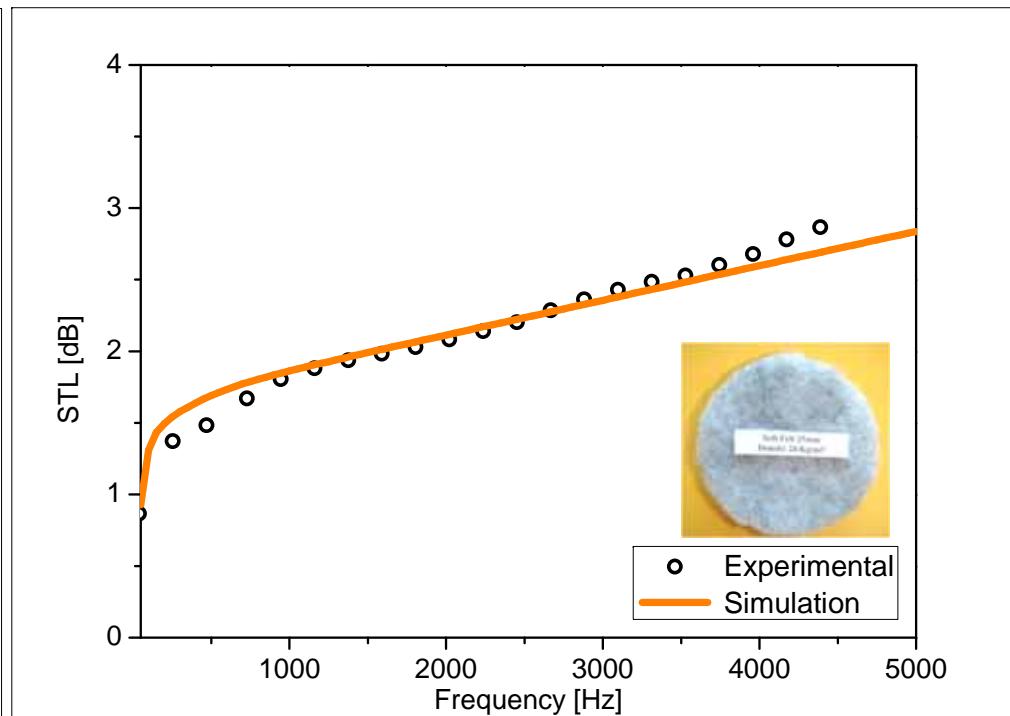
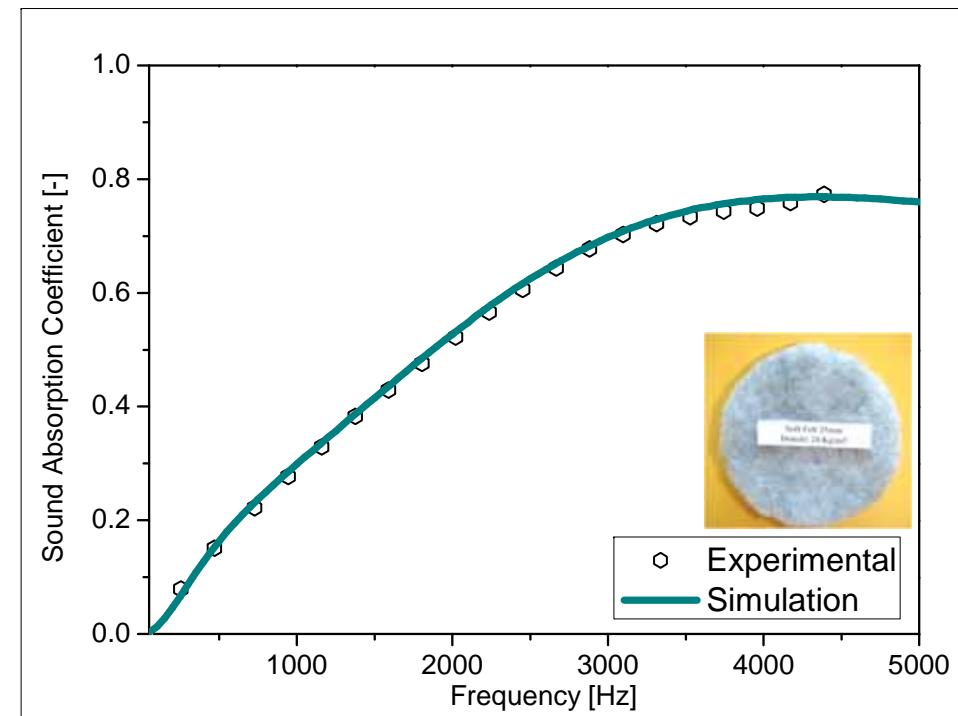


# Test Results - Soft Felt 25 mm-24kg/m<sup>3</sup>

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[33]

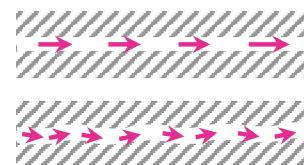
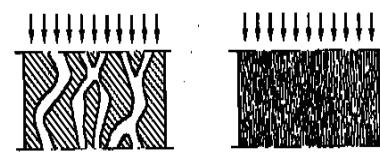
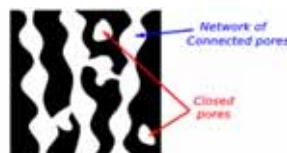
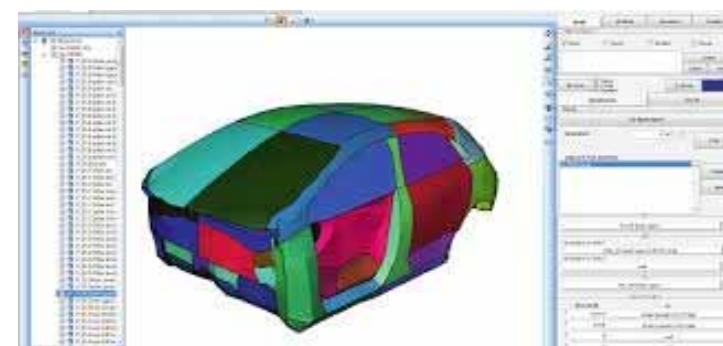


# Impedance Tube – Why 45 mm Tube for Industry?



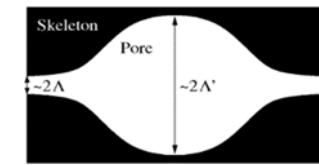
## Vehicle Level Simulation – Five Intrinsic Physical Parameters by Inversion (Biot Parameters)

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



$$\alpha_\infty = 1$$

$$\alpha_\infty > 1$$



# 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 2 <sup>nd</sup> Year	2 <sup>nd</sup> 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

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