UNIVERSITY OF NIŠ

FACULTY OF OCCUPATIONAL SAFETY

DEPARTMENT OF PREVENTIVE ENGINEERING

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WORKSHOP

Advanced Characterization of Acoustic Materials and Fire Performance

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Determination of Acoustic Material Properties Using the Transfer Function Method

Why do we characterize acoustic materials?

- Noise control in buildings
- Automotive acoustics
- Industrial noise control
- Environmental acoustics
- Occupational safety
- Material development

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Sound absorption vs Sound insulation

- Sound absorption coefficient α is the fraction of incident acoustic energy that is absorbed by a material when sound waves hit it at normal incidence inside an impedance tube.

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

$R -$ complex reflection coefficient at the sample surface

$\alpha = 0 \rightarrow$ total reflection (no absorption)

$\alpha = 1 \rightarrow$ total absorption (no reflection)

- Sound transmission loss (TL) is a measure (in decibels) of how much sound energy is blocked (not transmitted) through a material.

$$TL = 10 \log\left(\frac{1}{\tau}\right)$$

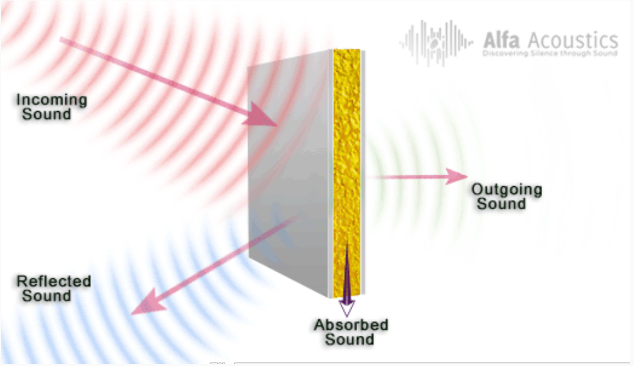
$\tau -$ transmission coefficient (ratio of transmitted to incident sound power)

High TL $\rightarrow$ good sound insulation

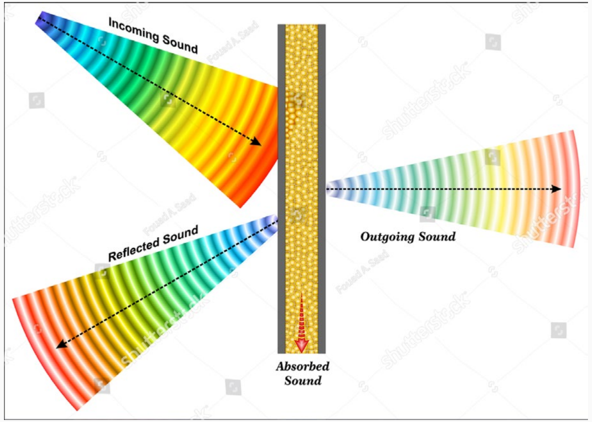
Low TL $\rightarrow$ poor sound insulation

Physical meaning

- Sound interaction with a surface:
- reflection;
- absorption;
- transmission.



- Acoustic quantities for characterizing acoustic materials:
- surface impedance;
- surface admittance;
- sound reflection coefficient;
- sound absorption coefficient;
- sound transmission loss.



Contents

01 Standards

Introduction

- There are two standrads for the measurement of acoustical properties of materials: ASTM E1050 and ISO 10534-2. Both describe what has come to be known as “two-microphone” or “transfer-function” method of measuring absorption and impedance of acoustical materials.
- Impedance tube method enables controlled laboratory measurements.
- Laboratory measurements of sound absorption coefficients were conducted using an impedance tube, following the test method outlined in ISO 10534 – Determination of acoustic properties in impedance tubes – Part 2: Transfer-function method using large impedance tube.

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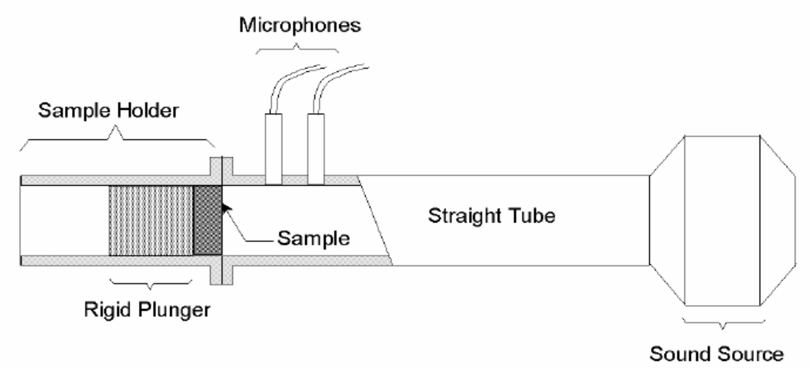
Test method – ISO 10534-2:2023

- The Two-Microphone Method – a sample of the material to be tested is placed in a sample holder and mounted to one end of a straight tube. A rigid plunger with an adjustable depth is placed behind the sample to provide a reflecting surface. A sound source, typically a high-output acoustic driver, is connected at the opposite end of the tube. A pair of microphones is mounted flush with the inner wall of the tube near the sample end of the tube.



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Test method – ISO 10534-2:2023

- The test sample is mounted at one end of the straight, rigid, smooth and airtight impedance tube. Plane waves are generated in the tube by a random sound source and the sound pressures are measured at two locations near the sample.
- The two-microphone method of measuring the sound absorption coefficient involves the decomposition of a broadband stationary random signal into its incident (p_i) and reflected (p_r) components. The signal is generated by a sound source, and the incident and reflected components are determined from the relationship between the acoustic pressure measured by microphones at two locations on the wall of the tube.

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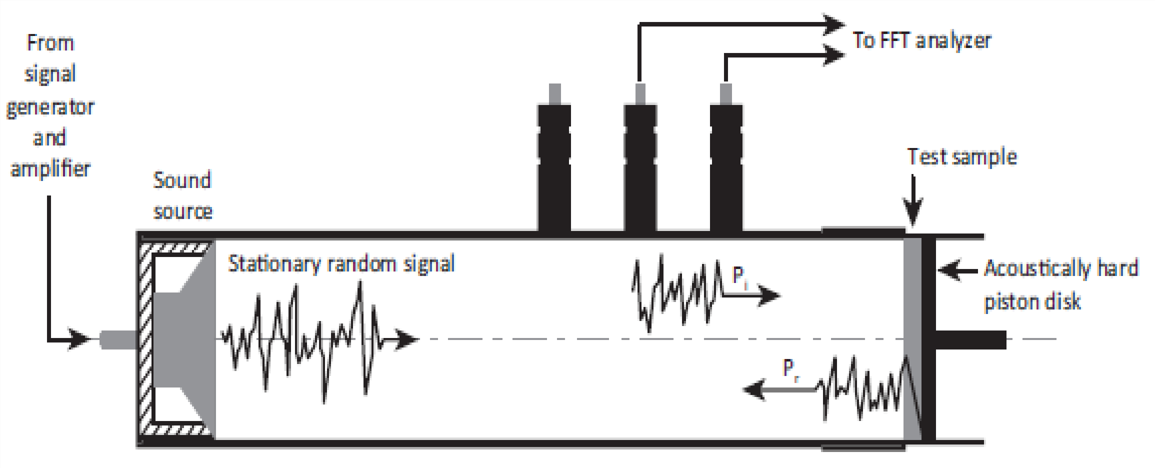
Test method – ISO 10534-2:2023



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Test method – ISO 10354-2:2023

- From the incident and reflected components of the sound pressure at the two microphone positions, three frequency response functions are calculated: $\underline{H}_1$ – the frequency response function, $\underline{H}_i$ – the frequency response function associated with the incident component and $\underline{H}_r$ – the frequency response function associated with the reflected component.

$$\underline{R} = \left(\frac{\underline{H}_1 - \underline{H}_i}{\underline{H}_r - \underline{H}_1} \right) e^{2jk(l+s)}$$

k is the wave number, ***l*** is the distance between the first microphone location and the front side of the sample (in mm), and ***s*** represents spacing between the microphones (in mm).

- Using this value for the reflection coefficient $\underline{R}$, the normalized impedance ratio $\left(\frac{z}{\rho c}\right)$ and the sound absorption coefficient (α) can be calculated:

$$\frac{\underline{z}}{\rho c} = \frac{1+\underline{R}}{1-\underline{R}} \qquad \alpha = 1 - \left|\underline{R}\right|^2$$

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Test method – ISO 10354-2:2023

- During the calibration procedure, the calibration frequency response functions for the microphones in the standard positions ($\underline{H}_{C1}$) and the interchanged positions ($\underline{H}_{C2}$) are calculated. From these values, the calibration factor ($\underline{H}_C$) is calculated as:

$$\left|\underline{H}_C\right| = \sqrt{\left|\underline{H}_{C1}\right| \cdot \left|\underline{H}_{C2}\right|}$$

$$\phi_C = \frac{1}{2}\left(\phi_{C1} + \phi_{C2}\right)$$

$$\underline{H}_C = \left|\underline{H}_C\right| e^{j\phi_C}$$

- For the frequency response function measured with the microphones in the standard postions:

$$\underline{H} = \left|\underline{H}\right| e^{j\phi}$$

$$\left|\underline{H}_1\right| = \frac{\left|\underline{H}\right|}{\left|\underline{H}_C\right|}$$

$$\phi_h = \phi - \phi_C$$

$$\underline{H}_1 = \frac{\underline{H}}{\underline{H}_C} e^{j\phi_h}$$

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Signal to Noise Ratio

- Accurate measurements of material absorption require that the sound field be substantially larger than the background noise inside the tube. The minimum signal-to-noise ratio will occur at the minima of the standing waves; these minima can be as much as 25 dB below the maximum levels in the tube.
- The standard recommend that the level of sound in the tube be at least 10 dB greater than the background noise level, but 20-30 dB is preferred. Taken together, these conditions require a background noise level in the tube in the 10-20 dB range. To achieve this low background level, the tube must be constructed of heavy materials and must be sealed properly at all openings (microphone ports, sample holder, sound source, etc.)

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Construction of the Tube

- The tube should be massive and sufficiently rigid to avoid
  - Transmission of noise into tube from outside and
  - Vibration excitation by the sound source or from background sources
- The tube must be sufficiently long to present a stable plane-wave sound field to the sample under test. All sound sources produce spherical waves that decay into plane waves over distance inside a tube. However, this distance can be quite long for large-diameter tubes. The standard recommend a tube length of at least three diameters; a length of at least 10-15 diameters is preferred.

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Microphone and Mounting

- The microphones must be mounted flush with the inside wall of the tube and isolated from the tube (to minimize sensitivity to vibration). Microphones isolated within a specially designed microphone holder that is also isolated from the tube provide the best results.
- The particular microphones used are not important as long as they are laboratory grade and are the same type and size (typically ½ and ¼ inch microphones are used).

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Sound Source

- The sound source shoud provide sound energy over a frequency and intensity range sufficient for testing.
- The frequency response of the source shouldn't be flat.
- It is usually important for the sound source to have a high-power rating, so that high intensity sound may be generated inside the tube for certain types of testing.

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Mounting the Sample

- According to standard the sample must fit snugly into the specimen holder, not so tightly that it bulges in the center, nor so loosely that there is space between its edge and the holder.
- Pliable materials such as foams and glass fiber are easy to cut slightly undersize and sealed around the edges using vaseline or wrapped with a couple of layers of tape to eliminate gap between the sample and the tube.
- The goal is to achieve a very slight interference fit between the sample and the holder.
- The sample must also be in contact with the rigid plunger. An air gap will affect the results.

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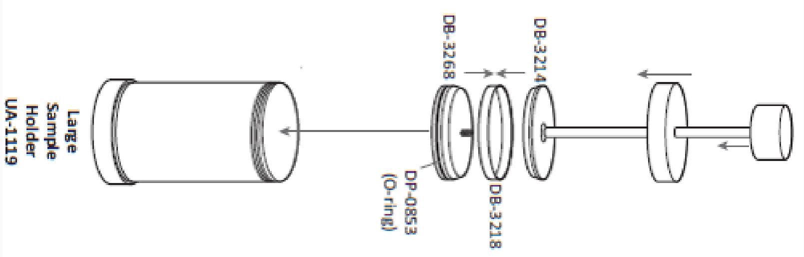
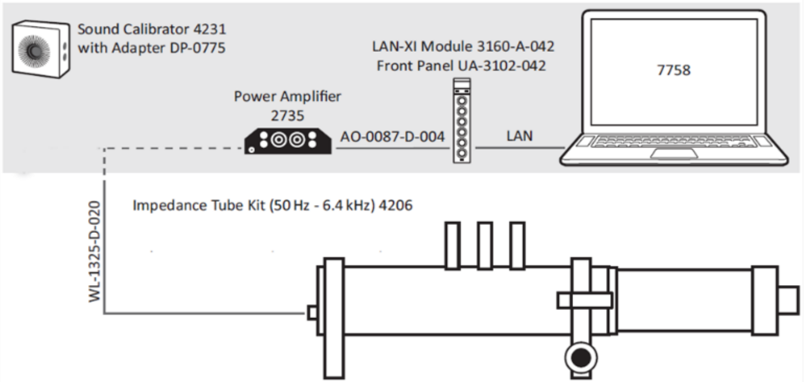
02 Measurement setups

Measurement setup – Large Tube

- The test samples were snugly fitted in the large sample holder UA-1119. The sample holders consist of an aluminium tube, open at one end, through which a piston arrangement can be moved back and forth. The large tube has a groove onto which the securing clips of the adjustable foot are attached. The front surface of the test specimens was mounted normal to the tube axis. Measurement setup used for testing in the frequency range from 50 Hz to 1600 Hz.





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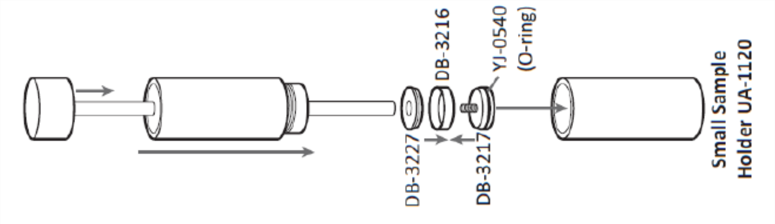
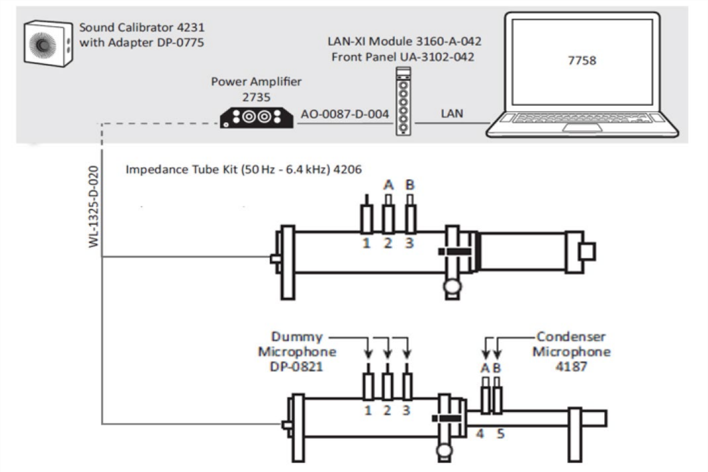
Measurement setup – Small Tube

- The test samples were snugly fitted in the small sample holder UA-1120. The sample holders consist of an aluminium tube, open at one end, through which a piston arrangement can be moved back and forth. The small tube has a groove onto which the securing clips of the adjustable foot are attached. The front surface of the test specimens was mounted normal to the tube axis. Measurement setup used for testing in the frequency range from 500 Hz to 6400 Hz.





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Measurement and impedance tube parameters

The following tables provide detailed information on the parameters used during the impedance tube measurements. Each set of parameters was carefully selected to ensure accurate and reliable measurement results.

	Large tube	Small tube
Microphone spacing	0.05 m	0.02 m
Distance to Sample from Mic. A	0.1 m	0.15 m
Distance to Sample from Mic. B	0.05 m	0.035 m
Distance to Source from Mic. B	0.35 m	0.59 m
Distance to Source from Mic. A	0.30 m	0.57 m
Diameter	0.1 m	0.029 m
Lower Frequency Limit	50 Hz	500 Hz
Upper Frequency Limit	1600 Hz	6400 Hz

	Large tube	Small tube
Span	1600 Hz	6400 Hz
Number of lines	800	3200
Number of averages	150	150
Frequency resolution	2 Hz	2 Hz

Waveform	Random
Signal Level	1.414 Vrms

Signal-to-Noise ratio below	10 dB
Autospectrum (Max-Min) above	60 dB
Calibration Factor exceeds	± 2 dB, ± 2°

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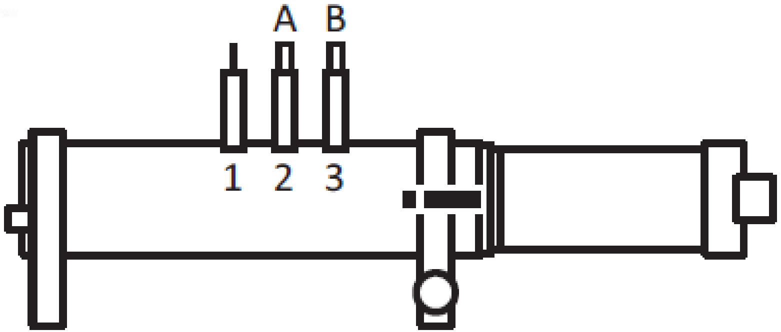
Standard Large Tube Setup

Standard large tube setup



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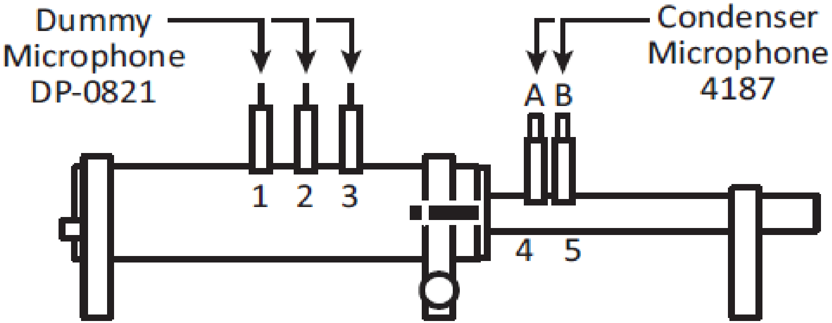
Standard Small Tube Setup



Standard small
tube setup

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03 Test results

Tested Samples

Identification	Description	Bulk density (measured) [kg/m^3]
Sample 1	Cellular material based on NBR (nitrile butadiene rubber) rubber (sample with grinded front surface)	274.5
Sample 2	Open-cell material obtained by hot-pressing from TPE (Thermoplastic Elastomer) granules (high bulk density)	486.9
Sample 3	Open-cell material obtained by hot-pressing from TPE granules (low bulk density)	315.4
Sample 4	Closed-cell material based on TPE	91.3
Sample 5	Cellular material based on NBR rubber (sample with non-grinded front surface)	292.4
Sample 6	Cellular material based on NBR rubber (sample with non-grinded front surface)	286.6
Sample 7	Closed-cell material based on high density polyurethane foam	372.4
Sample 8	Non-woven material based on flax and polypropylene fibers	129.2
Sample 9	Open-cell material obtained by hot-pressing foam polyurethane foam granules	205.3
Calibration sample	Open-cell material based on standard density polyurethane foam	25.9

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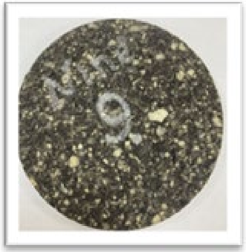
Tested Samples



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Test results

The test results – the sound absorption coefficient for normal sound incidence per one-third octave from 50 Hz to 6300 Hz.

f (HZ)	Sample 1	Sample 2	Sample 3	Sample 4	Sample 6	Sample 7	Sample 8	Sample 9
50	0.03	0.04	0.04	0.04	0.04	0.05	0.04	0.03
63	0.03	0.03	0.04	0.04	0.05	0.03	0.04	0.03
80	0.04	0.04	0.04	0.04	0.05	0.04	0.04	0.04
100	0.05	0.04	0.04	0.04	0.06	0.05	0.05	0.05
125	0.02	0.01	0.01	0.01	0.04	0.01	0.02	0.01
160	0.04	0.04	0.03	0.03	0.06	0.03	0.03	0.03
200	0.04	0.05	0.04	0.03	0.07	0.04	0.03	0.04
250	0.05	0.08	0.06	0.04	0.08	0.05	0.04	0.04
315	0.06	0.09	0.08	0.04	0.09	0.05	0.05	0.05
400	0.07	0.12	0.10	0.04	0.09	0.06	0.07	0.06
500	0.08	0.17	0.14	0.05	0.10	0.07	0.08	0.09
630	0.09	0.20	0.21	0.05	0.12	0.07	0.11	0.12
800	0.10	0.24	0.29	0.06	0.16	0.09	0.14	0.17
1000	0.12	0.29	0.37	0.07	0.22	0.13	0.18	0.25
1250	0.14	0.36	0.45	0.08	0.25	0.15	0.21	0.34
1600	0.15	0.48	0.56	0.07	0.24	0.24	0.23	0.46
2000	0.16	0.50	0.61	0.08	0.22	0.22	0.30	0.60
2500	0.18	0.47	0.56	0.11	0.20	0.17	0.40	0.75
3150	0.19	0.45	0.49	0.15	0.18	0.15	0.53	0.84
4000	0.21	0.47	0.45	0.13	0.17	0.14	0.69	0.87
5000	0.23	0.51	0.46	0.11	0.20	0.14	0.84	0.85
6300	0.25	0.55	0.47	0.10	0.21	0.13	0.92	0.80

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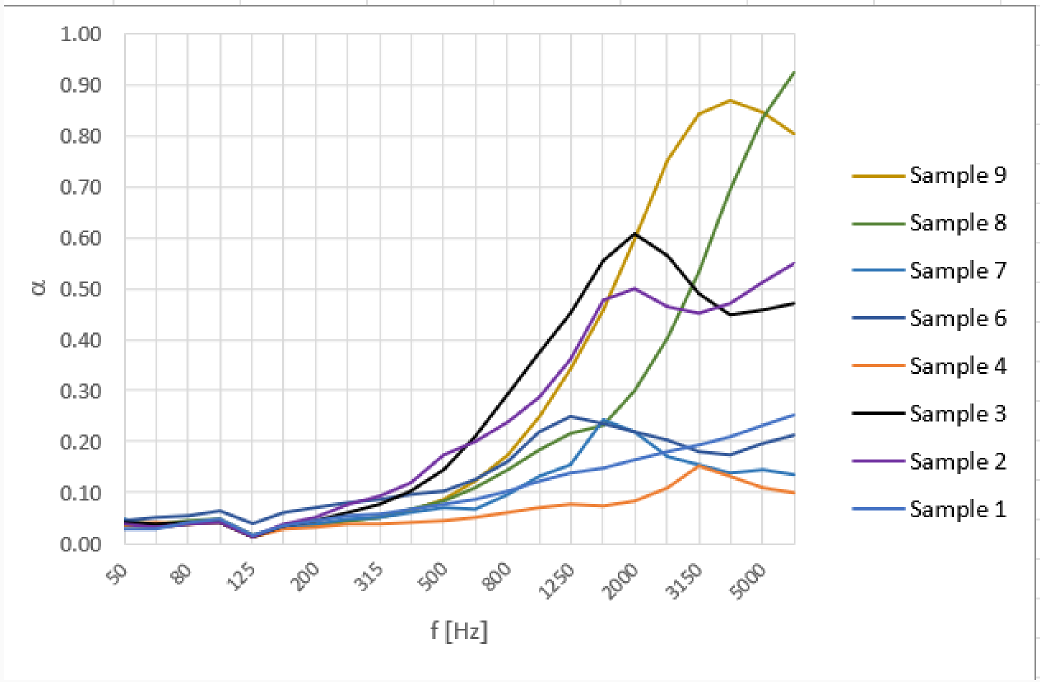
Test results

Sound absorption coefficient for normal sound incidence per one-third octave from 50 Hz to 6300 Hz for all tested samples.



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Determination of Acoustic Material Properties Using the Transfer Matrix Method

Contents

01 Standards

Introduction

- Laboratory measurements of sound transmission loss coefficients were conducted using an impedance tube, following the test method outlined in ASTM E2611-2019: Standard Test Method for Normal Incidence Determination of Porous Material Acoustical Properties Based on the Transfer Matrix Method.

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Measured properties of materials – assuming anechoic termination

T_a – Normal incidence pressure transmission coefficient

R_a – Normal incidence pressure reflection coefficient

$T_{\Pi a}$ – Normal incidence, power transmission coefficient

$R_{\Pi a}$ – Normal incidence, power reflection coefficient

α_{na} – Normal incidence absorption coefficient

α_{nd} – Normal incidence dissipation coefficient

Z_a – Surface normal incidence impedance

TL_n – Normal incidence transmission loss

K_p – Complex wave number of the material

Z_p – Complex characteristic impedance of the material

C – Normalized complex sound speed of the material

C_{ph} – Normalized phase speed of the material

P – Normalized complex density of the material

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Measured properties of materials – assuming hard backing

R_h – Normal incidence pressure reflection coefficient

α_{nh} – Normal incidence absorption coefficient

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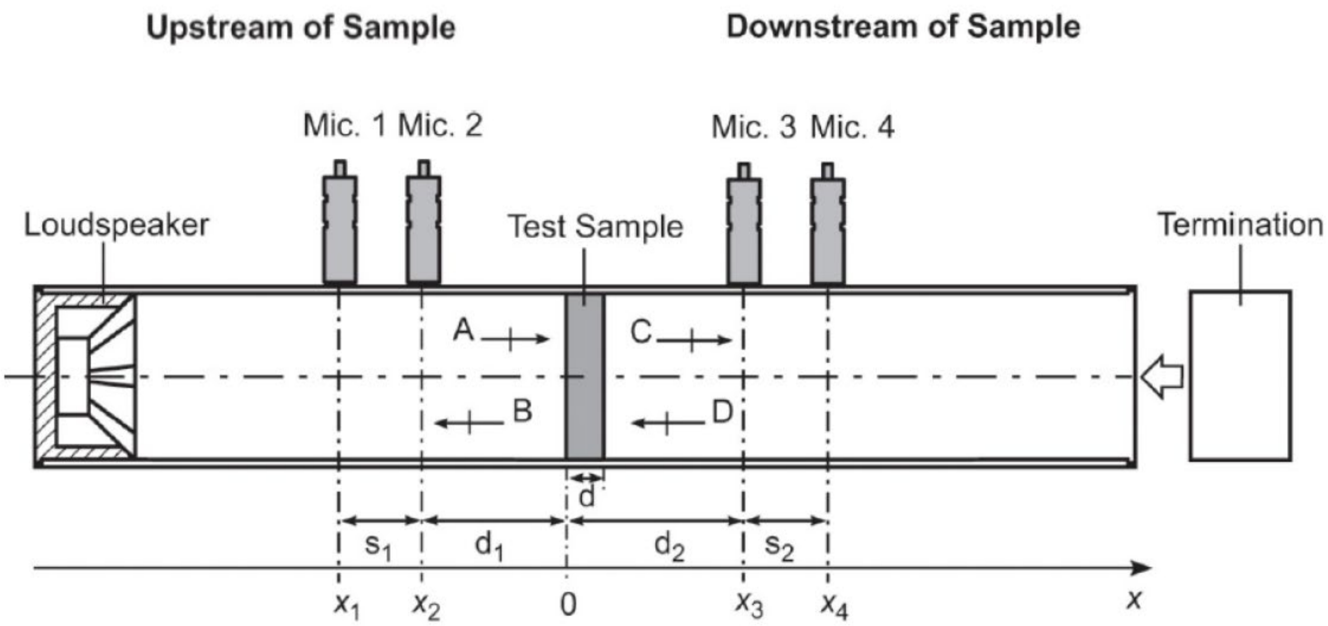
Theoretical background – ASTM E2611-2019



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Theoretical background – ASTM E2611-2019

- The method involves the determination of the transfer matrix, which relates the exterior, complex pressures, *P*, and the exterior, complex normal acoustic particle velocities, *V*, on the two faces of the acoustic element.

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

- Transfer matrix components, which are independent of the tube termination conditions, may be directly related to the sample normal incidence, sound transmission loss and other acoustical properties of the sample.

- In the frequency range where only plane waves can propagate in the tube, the sound field generated by the loudspeaker in each of the two tube sections can be modeled as the sum of two plane waves propagating in opposite directions.

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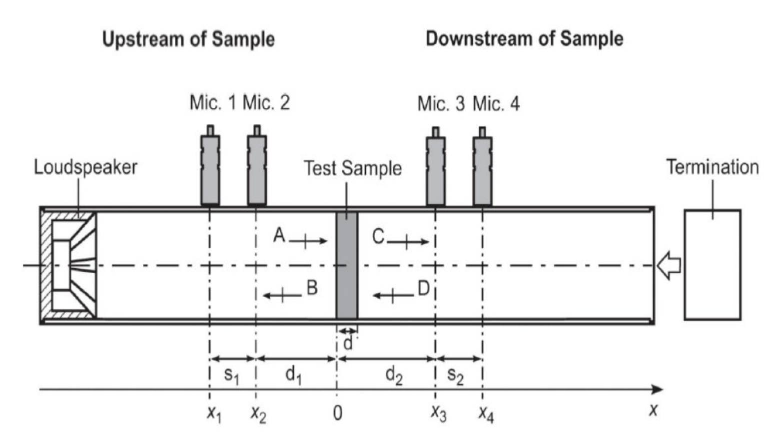
Theoretical background – ASTM E2611-2019



A – propagated plane wave upstream of sample

B – retro-propagated plane wave upstream of sample

C – propagated plane wave downstream of sample

D – retro-propagated plane wave downstream of sample

The complex pressures, P, and the complex normal acoustic particle velocities, V, on the two faces of the sample can then be obtained by the decomposition of the sound field into propagated and retro-propagated plane wave components for both sections.

- Procedure

– the components A, B, C and D are calculated based on:

$$\underline{A} = j\frac{\underline{H}_{1,\text{ref}}e^{-jkl_1} - \underline{H}_{2,\text{ref}}e^{-jk(l_1 - s_1)}}{2\sin(ks_1)} \qquad \underline{C} = j\frac{\underline{H}_{3,\text{ref}}e^{jk(l_2 + s_2)} - \underline{H}_{4,\text{ref}}e^{jkl_2}}{2\sin(ks_2)}$$

$$\underline{B} = j\frac{\underline{H}_{2,\text{ref}}e^{jk(l_1 + s_1)} - \underline{H}_{1,\text{ref}}e^{jkl_1}}{2\sin(ks_1)} \qquad \underline{D} = j\frac{\underline{H}_{4,\text{ref}}e^{-jkl_2} - \underline{H}_{3,\text{ref}}e^{-jk(l_2 - s_2)}}{2\sin(ks_2)}$$

– sound pressure and particle velocity on both faces of the sample are determined as:

$$\underline{p}_{x=0} = \underline{p}_0 = \underline{A} + \underline{B}, \qquad \underline{p}_{x=d} = \underline{p}_d = \underline{C}e^{-jkd} + \underline{D}e^{jkd},$$

$$\underline{v}_{x=0} = \underline{v}_0 = \frac{\underline{A} - \underline{B}}{\rho c}, \qquad \underline{v}_{x=d} = \underline{v}_d = \frac{\underline{C}e^{-jkd} - \underline{D}e^{jkd}}{\rho c}.$$

– where ρc is the characteristic impedance of the air

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- Procedure

– Plane wave components A to D can be obtained from frequency response functions between the complex sound pressures at the microphones (with one of them used as a reference).

– The phases of the plane wave components are defined relative to the reference signal.

– A simultaneous measurement requires four channels, but it could be possible to use a minimum of two channels to acquire the necessary frequency response functions by moving one microphone in sequence and using the second signal as a reference.

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In previous version of this application, a different matrix representation, relating directly the propagated and retro-propagated plane wave components on both sides of the sample, has been used:

$$\begin{bmatrix} A \\ B \end{bmatrix} = \begin{bmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{bmatrix} \begin{bmatrix} C \\ D \end{bmatrix}$$

In that case, the normal incidence, sound transmission loss is:

$$TL_n = 10\log_{10}\left|\frac{A}{C}\right|^2_{x=0} = 20\log_{10}\left(t_{11}\right)$$

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In this version, a transfer matrix formulation as follows:

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

has been preferred, because it is better suited for extraction of material properties, such as complex wave number and complex characteristic impedance for limp or rigid materials.

Note the following equivalence:

$$\begin{bmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{bmatrix} = \begin{bmatrix} \frac{1}{2}\left(T_{11} + \frac{T_{12}}{\rho_0 c} + \rho_0 c T_{21} + T_{22}\right) e^{-jkd} & \frac{1}{2}\left(T_{11} - \frac{T_{12}}{\rho_0 c} + \rho_0 c T_{21} - T_{22}\right) e^{jkd} \\ \frac{1}{2}\left(T_{11} + \frac{T_{12}}{\rho_0 c} - \rho_0 c T_{21} - T_{22}\right) e^{-jkd} & \frac{1}{2}\left(T_{11} - \frac{T_{12}}{\rho_0 c} - \rho_0 c T_{21} + T_{22}\right) e^{jkd} \end{bmatrix}$$

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The normal incidence, sound transmission loss expressed in terms of transfer matrix elements is therefore:

$$TL_n = 10\log_{10}\left(\frac{1}{4}\left|T_{11} + \frac{T_{12}}{\rho_0 c} + \rho_0 c T_{21} + T_{22}\right|^2\right)$$

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Transfer function matrix method with four microphones

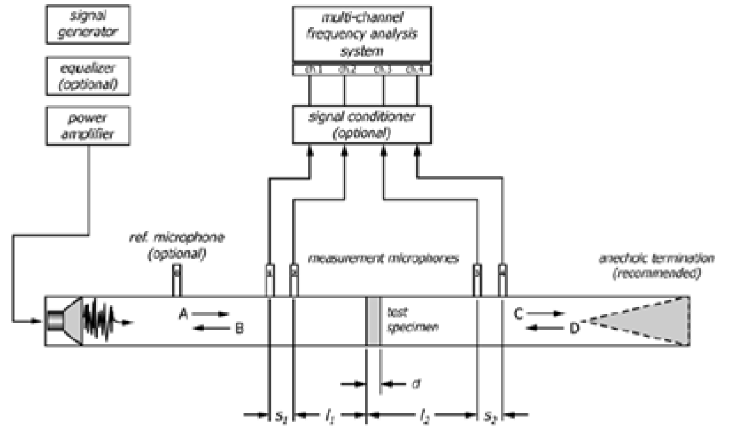
– ASTM E2611-2019

– measures: normal incident sound transmission loss, normal incidence sound absorption coefficient and sound reflection coefficient, the surface impedance and admittance

– similar to standing wave method with two microphones

– material sample is mounted in the middle part of the tube

– uses four microphones (two on each side of material sample)



Legend: A, B, C and D are the forward and backward components of the standing wave

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Two-load implementation

In order to be able to solve equation for the transfer matrix elements, two additional, independent equations are required.

By performing two measurements with different termination conditions, we can obtain four independent equations for determination of the four transfer matrix elements:

$$\begin{bmatrix} P^{(a)} & P^{(b)} \\ V^{(a)} & V^{(b)} \end{bmatrix}_{x=0} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} P^{(a)} & P^{(b)} \\ V^{(a)} & V^{(b)} \end{bmatrix}_{x=d}$$

where superscripts (a) and (b) denote the two different termination conditions.

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One-load implementation

In cases where the sample is symmetric in the sense that the plane wave reflection and transmission coefficients from the two surfaces of the sample are the same, it is possible to take advantage of the reciprocal nature of the layer to generate two additional equations instead of making a second set of measurements.

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

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

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Working Frequency Range

Lower working frequency (f_l) is limited by:

- The frequency resolution of the analysis system
- The frequency response of the loudspeaker
- The spacing between the microphones

$$0.01*\lambda_l < s \Rightarrow f_l > 0.01*\frac{c_0}{s} \quad \text{(ASTM E 2611)}$$

$f_l -$ lower working frequency [Hz]

$s -$ spacing between microphones [m]

$c_0 -$ speed of sound [m/s]

$$c_0 = 343.2\sqrt{\frac{T}{293}}$$

In theory, the lower working frequency could get close to zero, but in practice it is, however, determined by the quality of the analysis system and the physical length of the tube!

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Working Frequency Range

Upper working frequency (f_u) is limited by:

- The cross section of the tube

$$d < 0.586 * \lambda_u \Rightarrow f_u < 0.586 * \frac{c_0}{d}$$ Circular tube (ASTM E 2611)

$$d < 0.5 * \lambda_u \Rightarrow f_u < 0.5 * \frac{c_0}{d}$$ Rectengular tube (ASTM E 2611)

- The spacing between the microphones

$$s \leq 0.4 * \lambda_u \Rightarrow f_u \leq 0.4 * \frac{c_0}{s}$$ (ASTM E 1050)

d – inside diameter of circular tube [m] or max. side length of rectangular tube [m]

f_u – upper working frequency [Hz]

s – spacing between microphones [m]

c_0 – speed of sound [m/s]

$$c_0 = 343.2\sqrt{\frac{T}{293}}$$

The upper working frequency is chosen to avoid the occurrence of non-plane wave mode propagation and to assure accurate phase detection!

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The Impedance Tube

The tube must be long enough to cause plane wave development:

$$x_{ms} > d \text{ (minimum)}$$

$$x_{ms} > 3d \text{ (recommended)}$$

x_{ms} – the distance between source and closest microphone [m]

The spacing (l) between sample and closest microphone must be long enough to avoid proximity distortions to the acoustic field:

- Non-structured layer: $l > \frac{d}{2}$
- Semi-lateral structured layer: $l > d$
- Strongly asymmetrical layer: $l > 2d$

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The Microphones

- They must be placed in the plane wave field
- Their membrane diameter should be small in relation to their spacing to reduce the influence of their acoustic centers:

$$d_{mic} < 0.2 * s$$

- Their membrane diameter should be small to minimize high frequency spatial averaging across the diaphragm face:

$$d_{mic} \ll \lambda_u$$

d_{mic} – the diameter of the microphone

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02 Test procedure

Test procedure

It consists of:

- Preliminary Test and Calibration
- Test Specimen Mounting
- Determination of Settings
- Correction for bias-error
- Performing the measurements
- Post-processing
- Export of results and reporting

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Preliminary Test and Calibration

Prior to or following each test

- Microphone amplitude calibration $(\leq \pm 0.3\ dB)$
- Temperature $(\pm 0.5\ K)$ and air pressure measurement $(> 10\ dB)$
- Signal-to-noise ratio at each microphone position

Periodic calibration

- Correction for tube attenuation
- Correction for unequal acoustic and geometric center of the microphones

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Test Specimen Mounting

- The test specimen should fit snugly in the sample holder
- The front surface of flat test samples should be mounted normal to the tube axis
- A minimum of two specimens should be tested in repeated measurements using the same mounting conditions – more if sample is not uniform
- The test samples cuts should be along lines of symmetry of the structure
- For large multiple structured objects, several test samples with varying positons of the cuts relative to the structure should be used

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Determination of Settings

- Sound velocity, wavelength and characteristic impedance

$$c_0 = 343.2\sqrt{\frac{T}{293}}\left[\frac{m}{s}\right]$$

$$\lambda_0 = \frac{c_0}{f}\,[m]$$

$$\rho c_0 = \frac{c_0 \rho_0 p_a T_0}{p_0 T}\left[\frac{kg}{m^3}\right]$$

$T -$ Temperature [K]

$p_a -$ Atmospheric pressure [kPa]

$$T_0 = 293\,K;\;\; p_0 = 101.325\,kPa;\;\; \rho_0 = 1.186\,\frac{kg}{m^3}$$

- Pre-qualification of dynamic range

$$L_{p,\max} - L_{p,\min} < 60\,dB$$

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Types of Errors

- Random Errors
- Preparation and installation of test specimen (largest error)
- Bias Errors
    - Measurement distance from specimen
    - Different acoustic and geometric centers of microphones
    - Uncorrected phase and amplitude mismatch
    - Data acquisition and computational errors
- Time Aliasing
- Tube Attenuation
- Tube internal reflection
- Sample holder geometry

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Leakage

Leakage occurs if tube is not 100% airtight

- Low frequency leakage can occur at:
  - the mounting of the sample holder to the tube
- High frequency leakage can occur at:
  - the microphone mountings and the microphones themselves
- Leakage can be eliminated by:
  - a proper mechanical construction of the tube and microphones
  - the use of O rings

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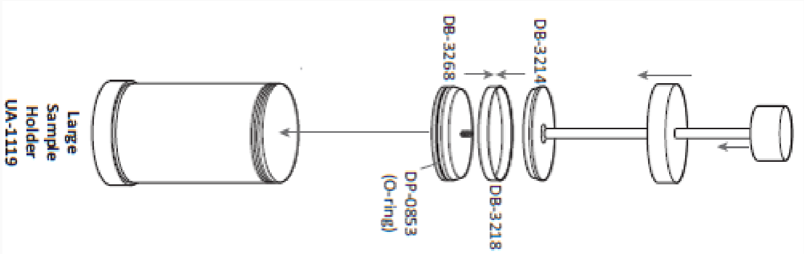
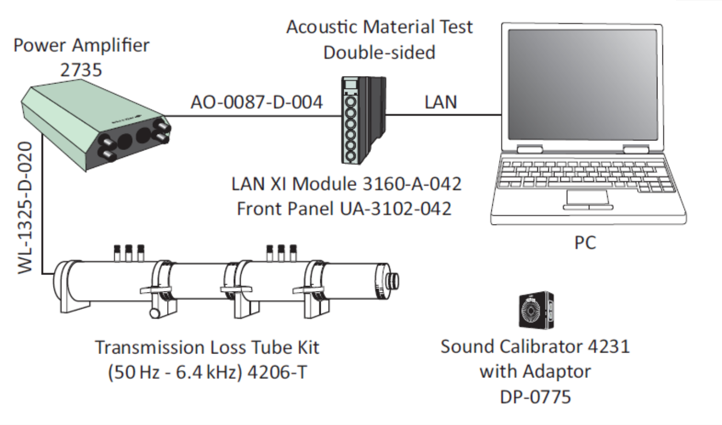
03 Measurement setups

Measurement setup – Large Tube

- The test samples were snugly fitted in the large sample holder UA-1119. The sample holders consist of an aluminium tube, open at one end, through which a piston arrangement can be moved back and forth. The large tube has a groove onto which the securing clips of the adjustable foot are attached. The front surface of the test specimens was mounted normal to the tube axis. Measurement setup used for testing in the frequency range from 50 Hz to 1600 Hz.





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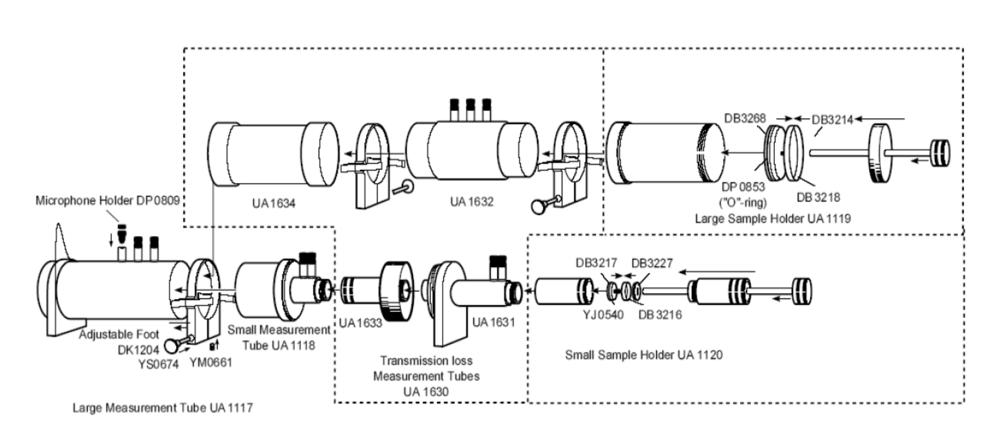
Measurement setup – Large and Small Tube

- The test samples were snugly fitted in the small sample holder UA-1120. The sample holders consist of an aluminium tube, open at one end, through which a piston arrangement can be moved back and forth. The small tube has a groove onto which the securing clips of the adjustable foot are attached. The front surface of the test specimens was mounted normal to the tube axis. Measurement setup used for testing in the frequency range from 500 Hz to 6400 Hz.



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Accessories

Accessories supplied with Type 4206 T

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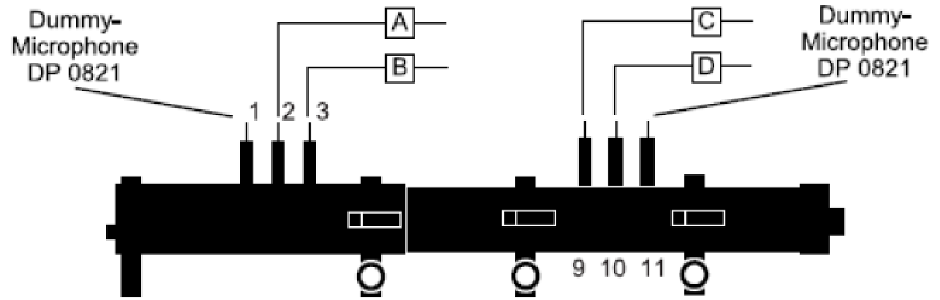
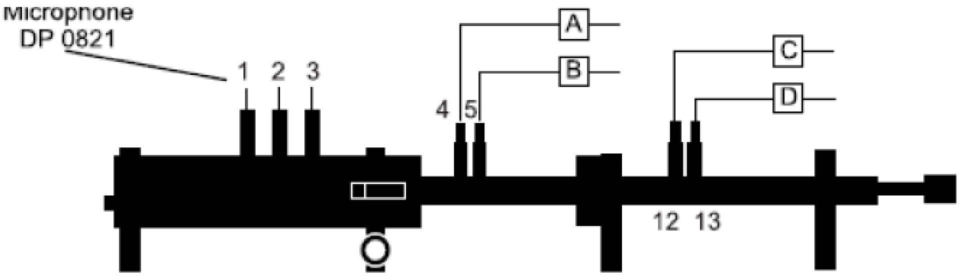
Standard Transmission Loss Configurations



Standard Transmission Loss large tube



Standard Transmission Loss small tube

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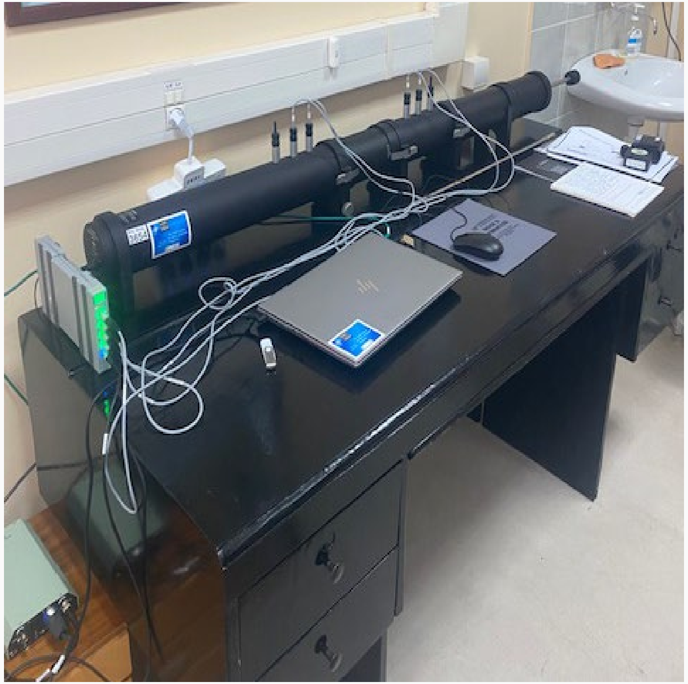
Standard Transmission Loss – Large Tube Setup



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Standard Transmission Loss – Small Tube Setup

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Specifications of Impedance Tube 4206 T

Tubes	Diameter [mm]	Length [mm]
Small Meas. Tube	29	550
Large Meas. Tube	100	800
Small Sample Holder	29	100
Large Sample Holder	100	150

Frequency Range

Large Tube: 50 Hz to 1.6 kHz

Small Tube: 500 Hz to 6.4 kHz

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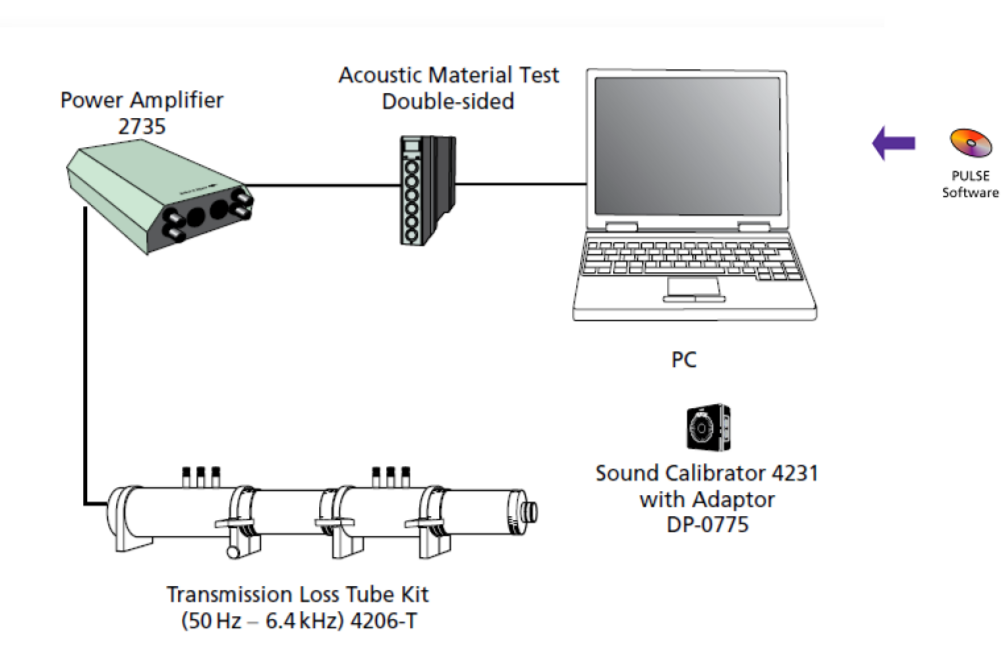
Recommended System Configuration



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04 Test results

Tested Samples

Identification	Description	Bulk density (measured) [kg/m^3]
Sample 1	Cellular material based on NBR (nitrile butadiene rubber) rubber (sample with grinded front surface)	274.5
Sample 2	Open-cell material obtained by hot-pressing from TPE (Thermoplastic Elastomer) granules (high bulk density)	486.9
Sample 3	Open-cell material obtained by hot-pressing from TPE granules (low bulk density)	315.4
Sample 4	Closed-cell material based on TPE	91.3
Sample 6	Cellular material based on NBR rubber (sample with non-grinded front surface)	286.6
Sample 8	Non-woven material based on flax and polypropylene fibers	129.2
Calibration sample	Open-cell material based on standard density polyurethane foam	25.9

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Tested Samples

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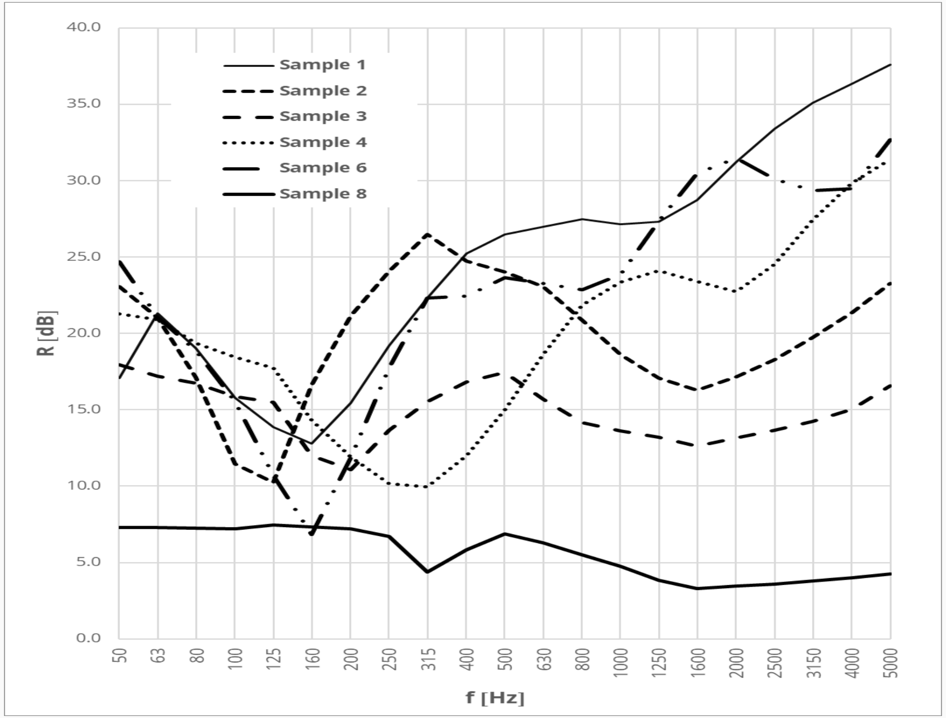
Test results

The test results, representing the normal incidence transmission loss per one-third octave, covering the frequency range from 50 Hz to 6300 Hz, are shown on the graph below.



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Thank you for your attention ！