Road Surface Absorption Measurement System

WA-1599

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Sound Absorption

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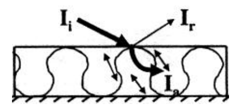
Absorber

- Absorber is a porous material, cellular or fibrous structure
- Activities inside the material include:
  - Viscous dissipation
  - Fibrous rub against each other
  - Sound energy transformed to thermal energy



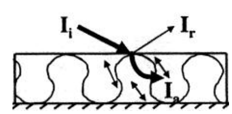
Performance is expected in terms of:

Sound Absorption Coefficient (α)

$$\text{Where,}\quad \alpha = \frac{\textbf{Sound energy absorbed} \text{ By a surface } (I_i - I_r)}{\text{Sound energy incident On that surface } (I_i)}$$

Absorber (continued)

- Coefficient varies from zero (0) to one (1)



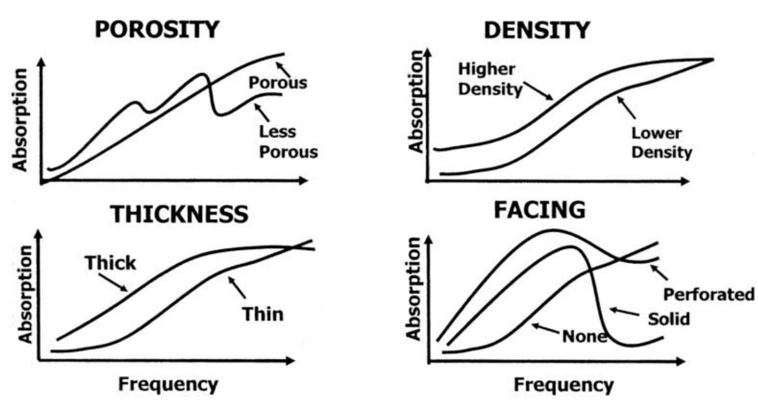
Performance is a function of frequency
  - Performed generally with the increase in frequency

- Performance improves with the increase in thickness
  - Material thickness: At least 1/10 wavelength of sound to justify the use (i.e., offer any benefit)
  - Material thickness: ¼ wavelength of sound to be effective

Absorption effect of various parameters

- Effect of porosity
- Effect of thickness
- Effect of density
- Effect of airspace between the absorber and the wall
- Effect of facing
  - No facing
  - Impervious membrane facing
  - Perforated facing
- Effect of perforation

Qualitative effect of various factors



Standardization

International Organization for Standardization
American Society for Testing and Materials

The Standards

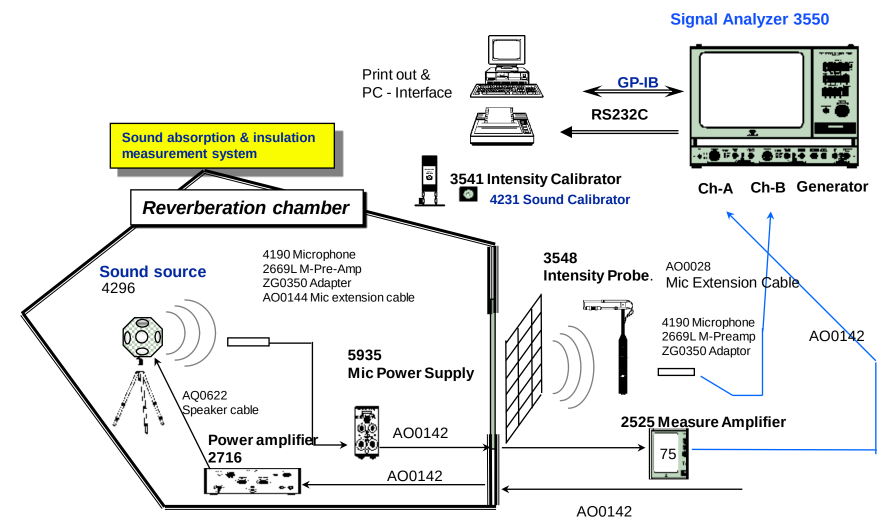
- **Reverberation Room Method**
  - ISO 354: 1985, Acoustics - Measurement of sound absorption in a reverberation room. Amendment (1998)
  - ASTM C 423-99a: Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method
- **Standing Wave Impedance Tube Method**
  - ISO 10534-1: 1996, Acoustics - Determination of sound absorption coefficient and impedance in impedance tubes - Part 1: Method using standing wave ratio
  - ASTM C 384-98: Standard Test Method for Impedance and Absorption of Acoustical Materials by Impedance Tube Method

The Standards (Cont.)

- **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 E 1050-98: Standard Test Method for Impedance and Absorption of Acoustical Materials Using A Tube, Two Microphones and A Digital Frequency Analysis System

The Standards (Cont.)

- **Free-field Method**
  - ISO 13472-1: Draft, Acoustics - Measurement of sound absorption properties of road surfaces in situ -
    Part 1: Extended surface method
  - ISO 13472-2: Draft, Acoustics - Procedure for measuring sound absorption properties of road surfaces in situ -
    Part 2: Spot method
- **Spatial Fourier Transform Method**
  - No known standard available. Not even on draft level.



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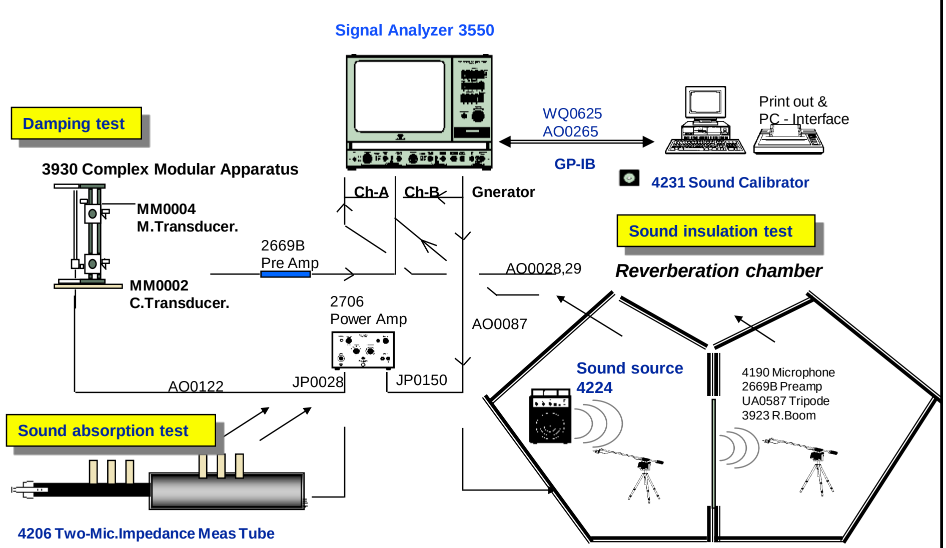

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The Two-microphone Method

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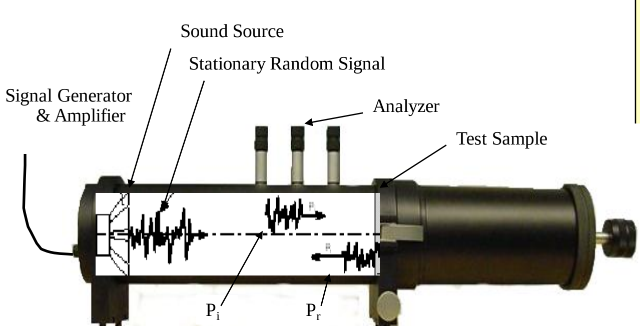
An Overview

- Broadband Random Noise Excitation
- Measurement of Sound Pressure (FFT)
- Calculation of Transfer Functions



Reflection Factor:

$$R = \frac{H_1 - H_i}{H_r - H_1} e^{j2k(l+s)} \quad [-], \text{ where}$$

H1 : Frequency Response Function (FRF)

Hi: FRF associated with the incident component

Hr: FRF associated with the reflected component

k: Wave number

l: Microphone distance to sample [mm]

s : Spacing between the microphones [mm]

Absorption Coefficient:

$$\alpha = 1 - |R|^2 \quad [-]$$

Normalized Impedance Ratio:

$$\frac{z}{\rho c} = \frac{1+R}{1-R} \quad [\ ]$$

ρc: Impedance of the Air [ ]

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Working Frequency Range

- **Lower working frequency (f_l) limited by:**
  - The frequency resolution of the analysis system
  - The frequency response of the loudspeaker
  - The spacing between the microphones
    - » $0.05*\lambda_l < s \Rightarrow f_l > 0.05*c_0/s$ (ISO 10534-2)
    - » $0.01*\lambda_l < s \Rightarrow f_l > 0.01*c_0/s$ (ASTM E 1050)

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Working Frequency Range

- **Upper working frequency (f_u) limited by:**
  - The cross section of the tube
    - » $d < 0.58*\lambda_u \Rightarrow f_u < 0.58*c_0/d$ (Circular tube) (ISO 10534-2)
    - » $d < 0.586*\lambda_u \Rightarrow f_u < 0.586*c_0/d$ (Circular tube) (ASTM E 1050)
    - » $d < 0.50*\lambda_u \Rightarrow f_u < 0.50*c_0/d$ (Rectangular tube) (ISO and ASTM)
  - The spacing between the microphones
    - » $s < 0.45*\lambda_u \Rightarrow f_u < 0.45*c_0/s$ (ISO 10534-2)
    - » $s <= 0.40*\lambda_u \Rightarrow f_u <= 0.40*c_0/s$ (ASTM E 1050)

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

f_l: lower working frequency [Hz]
f: operating frequency [Hz]
f_u: upper working frequency [Hz]
T: temperature [K]

d: inside diameter of circular tube [m]
max. side length of rectangular tube [m]
s: spacing between microphones [m]
c_0: speed of sound [m/s]
[$c_0 = 343.2*\mathrm{sqrt}(T/293)$]

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The Tube

- **The tube must be long enough to cause plane wave development:**
  - $x_{ms} > d$ (minimum)
  - $x_{ms} > 3d$ (recommended)

- **The spacing (l) between sample and closest microphone must be long enough to avoid proximity distortions to the acoustic field:**
  - Non-structured layer: $l > d/2$
  - Semi-lateral structured layer: $l > d$
  - Strongly asymmetrical layer: $l > 2d$

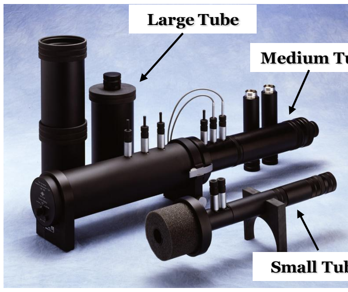
x_{ms}: The distance between source and closest microphone [m]

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:
  - $d_{mic} << \lambda_u$

d_{mic}: The diameter of the microphone

Specifications of Impedance Tube 4206



Tubes	d : Diameter [mm](in)	l : Length [mm](in)
Small Meas. Tube	29 (1.1)	200 (7.9)
Medium Meas. Tube	63.5 (2.5)	200 (17.4)
Large Meas. Tube	100 (3.9)	440 (17.4)
Small Sample Holder	29 (1.1)	200 (7.9)
Medium Sample Holder	63.5 (2.5)	200 (7.9)
Large Sample Holder	100 (3.9)	200 (7.9)
Small Ext. Tube	29 (1.1)	200 (7.9)
Large Ext. Tube	100 (3.9)	200 (7.9)

Frequency Range

Large Tube : 50Hz to 1.6kHz

Medium Tube : 100Hz to 3.2kHz

Small Tube : 500Hz to 6.4kHz

Zero Absorption

50Hz to 4kHz : <4%

5kHz to 6.4kHz : <10%

Calculated in 1/3-octave band

Types of Errors

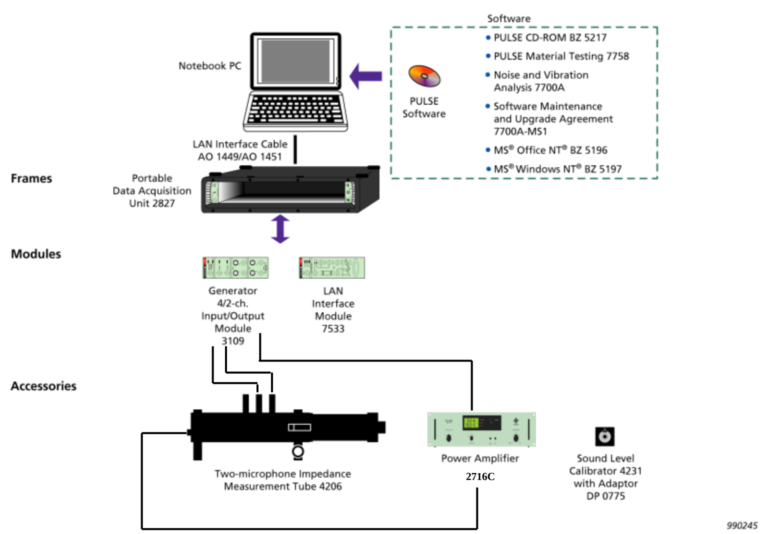
- Random Errors
- Bias Errors
  - Measurement distance from specimen
  - Different acoustic and geometric centers of microphones
  - Uncorrected phase and amplitude mismatch
  - Data acquisition and computational errors
- Preparation and installation of test specimen (largest error)
- Time Aliasing
-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

Leakage

Leakage occurs if the tube is not 100% airtight

- **Low frequency leakage can occur at:**
  - The mounting of the sample holder to the tube
  - The backplate in the sample holder
- **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”, where moving parts

System Configuration (Portable)



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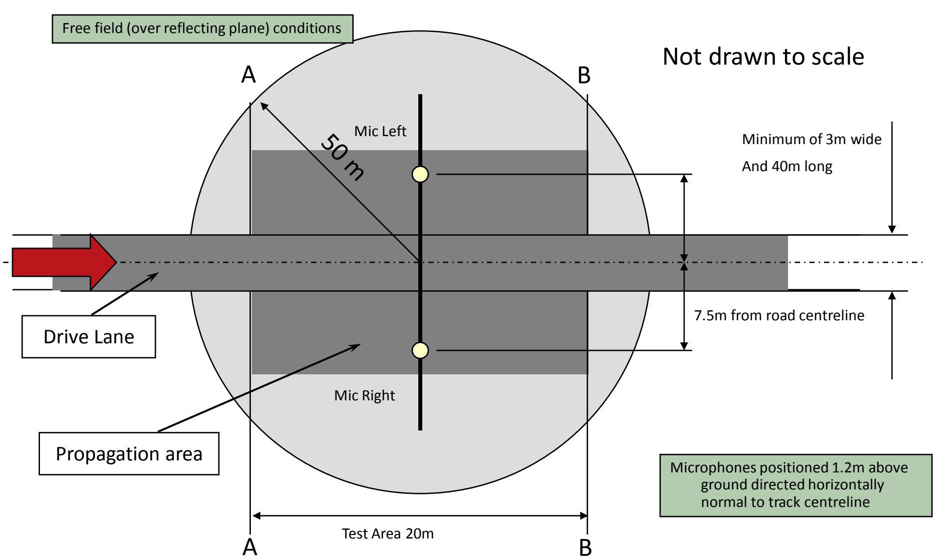
ISO Track Layout



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ISO 10844

ISO 10844 "Acoustics – Specification of test tracks for the purpose of measuring noise emitted by road vehicles and their tyres"

4.2 Surface properties of the propagation area

The surface of the propagation area shall exhibit a sound absorption value not exceeding 10 % on the average of the measurement points in any one-third-octave band between 315 Hz and 1 600 Hz when measured according to 5.3.

NOTE 1 The measure is realized on the site without taking cores

NOTE 2 Absorption level is the corrected result according to ISO 13472-2.

Location and number of measurement points are given in 4.4.

4.3 Surface properties of the drive lane

The surface of the drive lane:

a) shall be dense asphalt concrete and shall exhibit a sound absorption not exceeding 8 % of the measurement points in any one-third-octave band between 315 Hz and 1 600 Hz when measured according to 5.3.

ISO 10844

ISO 10844 "Acoustics – Specification of test tracks for the purpose of measuring noise emitted by road vehicles and their tyres"

4.4 Proving the requirements

..

For sound absorption, texture, geometrical and stiffness compliance, the first point shall be chosen randomly (not on the same axis) and the subsequent measurements shall be performed at 5 m intervals to cover the whole track.

..

All measurements shall be made along the total length of the drive lane in each wheel track.

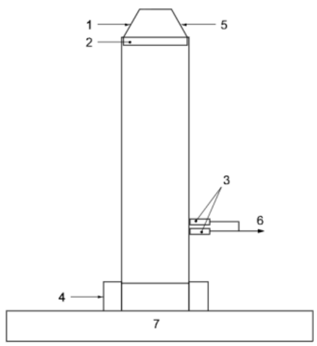
For checking the surface properties of the propagation area, take at least two measurements randomly chosen on each side.

In addition, sound absorption of the propagation area shall be measured at both sides of the drive lane at half way of the microphone location in the vicinity of the line PP'.

ISO 13472-2

ISO 13427-2 : "Acoustics — Measurement of sound absorption properties of road surfaces *in situ* —"

Part 2: **Spot method for reflective surfaces**



Key
1 loudspeaker
2 vibration isolation
3 microphones
4 *in-situ* test fixture
5 sound source and amplifier
6 frequency analyser
7 surface under test

ISO 13472-2

5.4 Impedance tube

5.4.1 Tube diameter

The diameter of the tube shall be (100 ± 1) mm. The tube shall have a circular cross-section, be straight with a uniform cross-section (variations in diameter no greater than 0,2 %) and with smooth, non-porous walls, without holes or slits and rigid so as to prevent unwanted loss of sound energy.

NOTE 1 Not meeting the diameter requirement affects the frequency range. The upper frequency at a given diameter, f_u, is given by the equation:

$$f_u = 0.58 * c_0 / d$$

where

c_0 is the speed of sound, in metres per second;

d is the diameter, in metres, of the tube.

NOTE 2 Loss of energy due to vibrations of the walls is generally prevented by using a metal tube with a thickness of at least 5 % of the tube diameter.

The tube shall have a small ventilation hole in the vicinity of the loudspeaker so as to prevent build-up of static pressure inside the tube.

ISO 13472-2

5.6 *In-situ* test fixture between impedance tube and test surface

Similar to a detachable holder (ISO 10534-2:1998, 4.7), an *in-situ* test fixture shall be fitted in such a way as to avoid air flowing between the end of the tube opposite the sound source and the surface to be measured. Any air leakage through this interface appears as absorption in the measurement results. The *in-situ* test fixture, like the detachable holder, shall conform to the interior shape and dimensions of the main part of the impedance tube. The connecting joint of the *in-situ* test fixture shall be finished carefully and shall exhibit no slit or hole. The use of a sealant, such as an O-ring, is required for sealing it to the main part of the impedance tube. Additionally, a groove shall be cut in the *in-situ* test fixture on the specimen side to accept a bead of sealing material such as water-soluble modeling clay, for sealing the fixture to the road.

Practically, the *in-situ* test fixture should have a larger outer diameter than the main part of the tube. The additional diameter is not used in the measurement, but this additional portion aids in stability when the system is mounted upright (see Annex C).

The sealing material shall fill irregularities due to surface texture but shall not penetrate into the surface and shall not spread out on the surface.

Measurement points :

For sound absorption, texture, geometrical compliance, the first point shall be chosen randomly (not on the same axis) on each side at the vicinity of the line PP' and the subsequent measurements shall be performed at 5 m intervals to cover the whole track.

ISO 13472-2

8. Measurement and analysis procedure

The measurement shall be carried out as follows:

a) check the road surface and meteorological conditions to ensure compliance with the specifications in Clause 7 — if these conditions are not met, the measurement cannot be carried out;

b) switch on the system for at least 15 min;

c) perform the microphone calibration procedure (6.2);

d) perform the reference measurement with a totally reflective surface (6.3);

e) place the measuring equipment on site as specified in 7.1, apply the sealant carefully in order to suppress measuring errors due to leakage, and check the correctness of the sealing visually or audibly;

f) perform the measurement: if online monitoring of the result is possible, proceed with averaging until a stable result is obtained — if this is not possible, averaging over 50 sweeps or bursts is recommended;

g) refer to ISO 10534-2 for procedures for measurement and calculation of both the sound pressure reflection factor and the sound absorption coefficient from the transfer function and tube geometry;

h) then compute the road surface sound absorption coefficient in one-third-octave bands (6.6);

i) repeat the measurements on at least four required positions and calculate the mean value and the standard deviation in each one-third-octave band;

j) compile the test report (see Clause 10 and Annex D).

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An Overview

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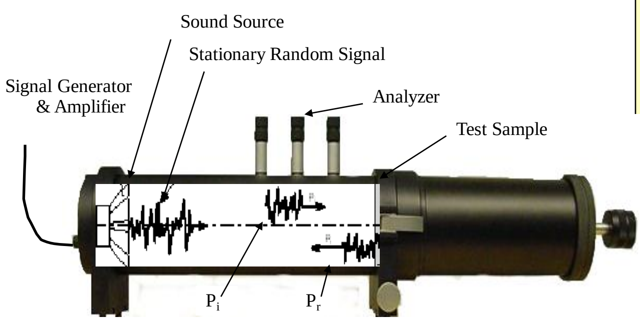


Reflection Factor:

$$R = \frac{H_1 - H_i}{H_r - H_1} e^{j2k(l+s)} \quad [-], \text{ where}$$

H1 : Frequency Response Function (FRF)

Hi: FRF associated with the incident component

Hr: FRF associated with the reflected component

k: Wave number

l: Microphone distance to sample [mm]

s : Spacing between the microphones [mm]

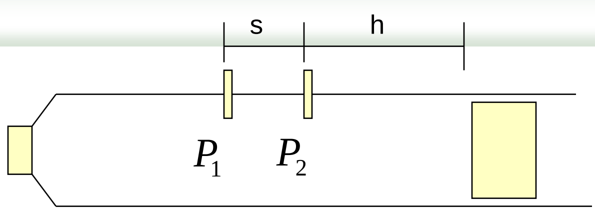
Absorption Coefficient:

$$\alpha = 1 - |R|^2 \quad [-]$$

Normalized Impedance Ratio:

$$\frac{z}{\rho c} = \frac{1+R}{1-R} \quad [\ ]$$

ρc: Impedance of the Air [ ]



$$H_{12} = \frac{P_2}{P_1} = \frac{e^{jkh} + \mathrm{Re}^{-jkh}}{e^{jk(h+s)} + e^{-jk(h+s)}}$$

$$R = \frac{H_{12} - e^{-jks}}{e^{jks} - H_{12}} e^{j2k(h+s)}$$

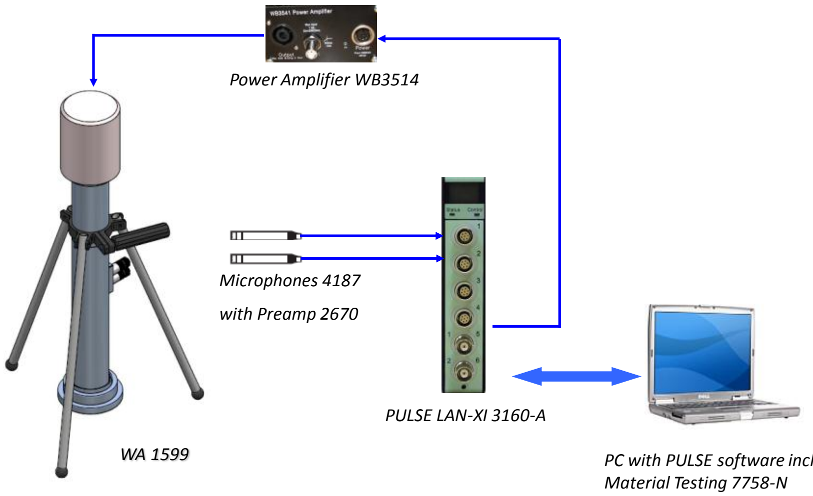
$$\alpha = 1 - |R|^2$$

H_{12} : Transfer Function between two microphones

R : Reflection Coefficient

α : Absorption Coefficient

System Configuration



Specifications of Tube WA 1599

- Working Frequency Range :

  1/3 Octave Analysis : 250 – 1,600 Hz Center frequency

  Narrow Band : 220 – 1,800 Hz

- Diameter of tube : 100 mm
- Shape of section : Circular