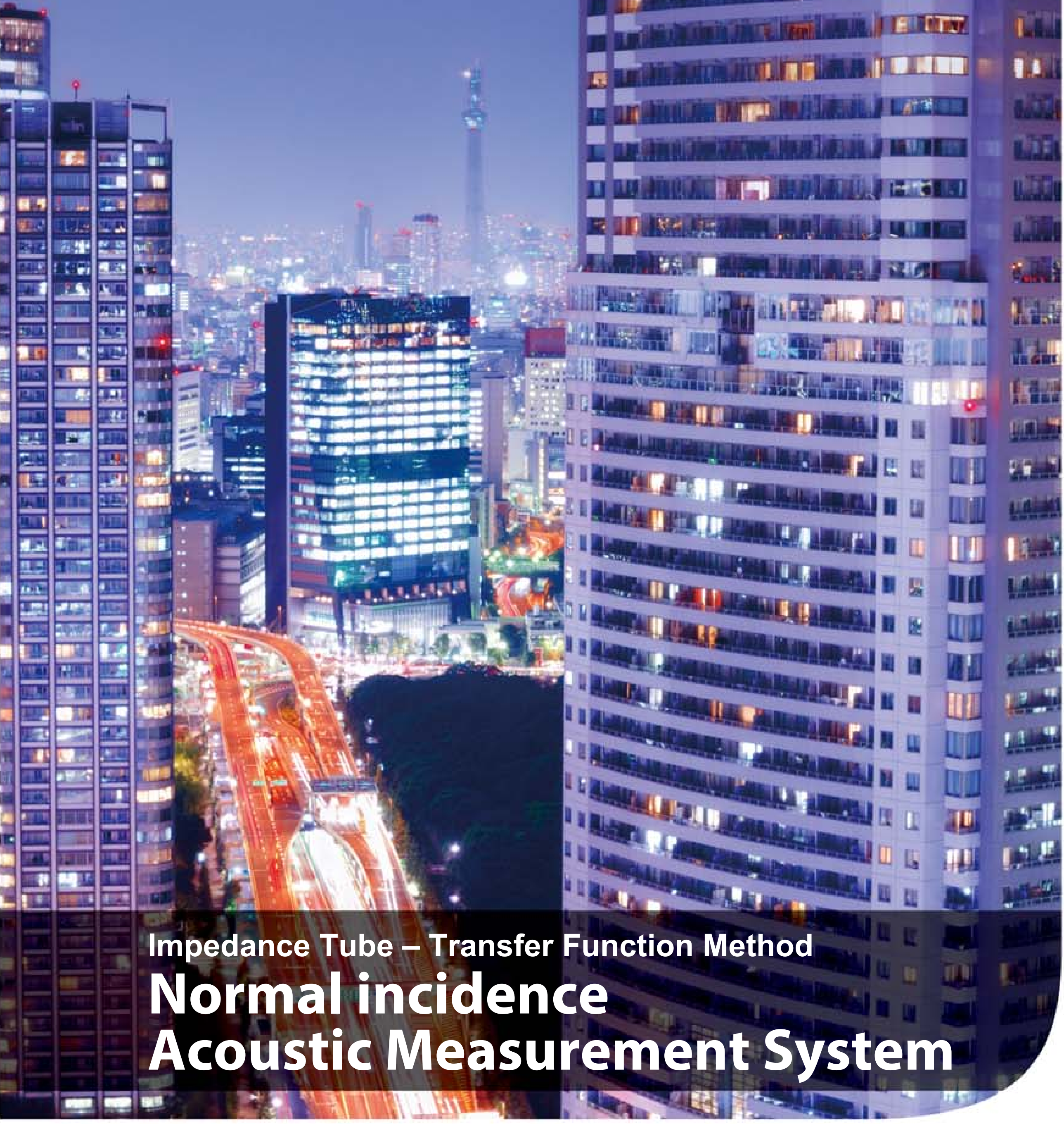


Impedance Tube – Transfer Function Method

Normal incidence Acoustic Measurement System

Model 9302

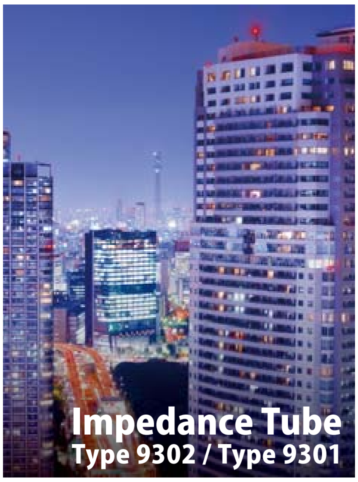
Normal incidence Sound absorption ratio measurement system

High Frequency tube | Low Frequency tube

Model 9301

Normal incidence Sound absorption ratio / Sound transmission loss measurement system

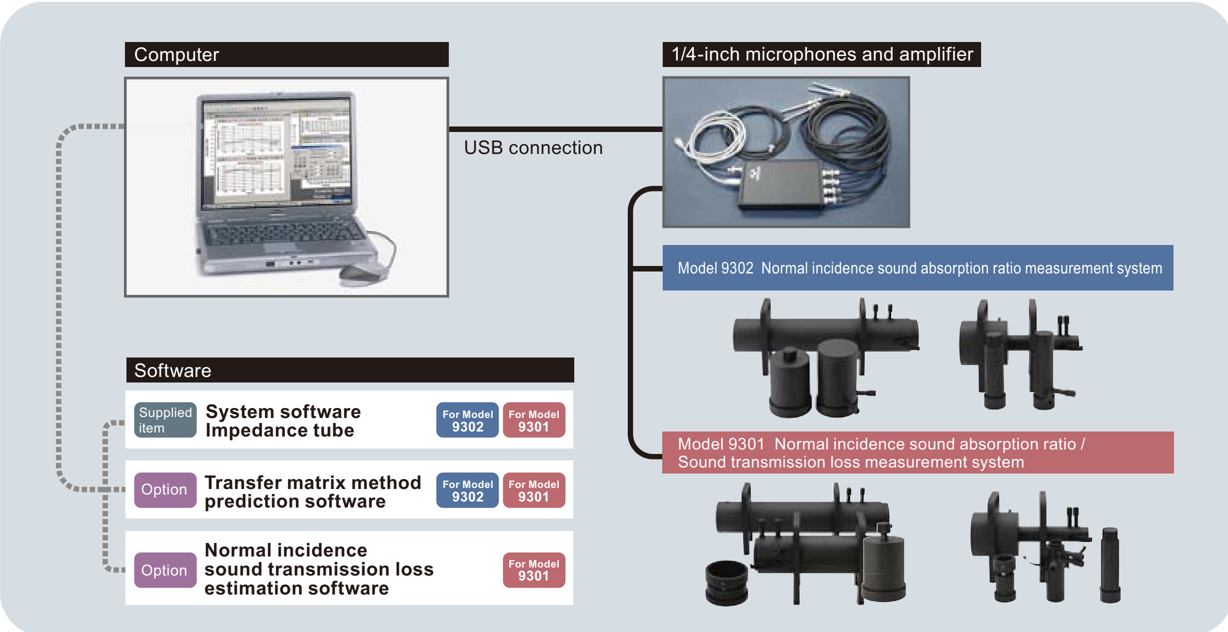
High Frequency tube | Low Frequency tube



This normal incidence acoustic measurement system captures reflected sound or transmitted sound produced by a source sound hitting a sound absorption material or sound insulation material normally. This is used to measure the sound absorption ratio, acoustic impedance, and related values, as well as the sound transmission loss of the material, for example to check acoustic characteristics during development or review of a material. The system measuring the sound absorption ratio is suitable for measurement of small-size test specimen with a diameter of up to 100 mm (108 mm when measuring the sound transmission loss). When dealing with acoustic materials such as sound absorption materials or sound insulation materials for automobiles or buildings, being able to quickly evaluate new materials or laminated materials is a crucial requirement during the development stage. The current system makes it easy to perform such evaluations by determining the physical characteristics of the material.
To accommodate different requirements, two types are available: Model 9302 and Model 9301.

Normal Incidence Acoustic Measurement System Using an Impedance Tube

Basic system configuration



Measurement system configuration and common elements

● Tube

Model 9302 Normal incidence sound absorption ratio measurement system
Low frequency tube (main section, calibration section, measurement section)
High frequency tube (main section, calibration section, measurement section)
Model 9301 Normal incidence sound absorption ratio / Sound transmission loss measurement system
Low frequency tube (main section, link section, calibration / measurement section, sound-absorption material measurement section)
High frequency tube (main section, link section, calibration / measurement section, sound-absorption material measurement section)

● Hardware

Set of 2 loudspeakers (integrated in low frequency or high frequency main tube)
1/4 inch microphones (2 for Model 9302, 4 for Model 9301)
Amplifier (microphone amplifier, A / D converter, signal source, power amplifier, power supply, USB link for communication)
Computer (Microsoft Windows 7 Professional 32 bit / 64 bit, 10 Pro 64 bit)

● System software

Impedance Tube (for Model 9302), Impedance Tube (for Model 9301)

● Optional software

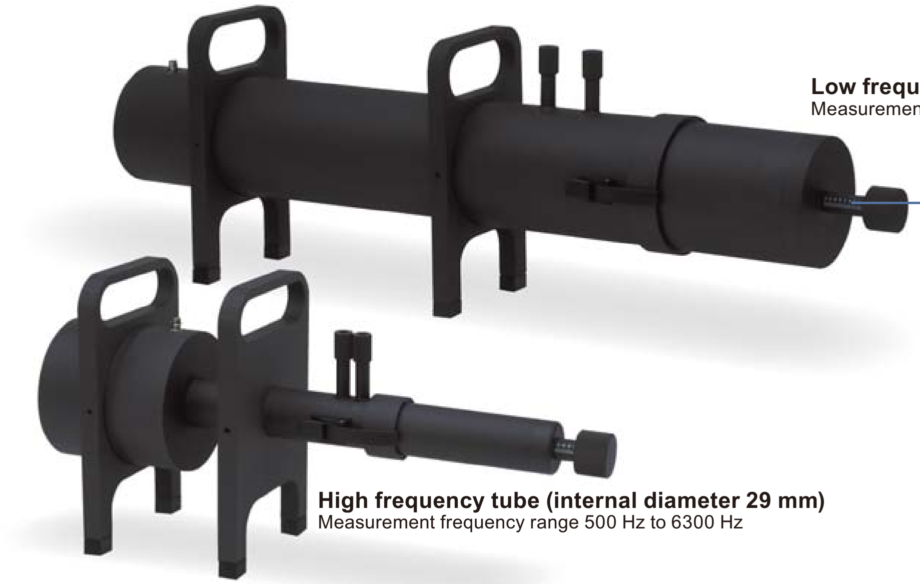
Transfer matrix method prediction software (made by Sound Environment Technology Laboratory) (for both Model 9302 and Model 9301)
Normal incidence transmission loss estimation software (made by Sound Environment Technology Laboratory) (for Model 9301)

This system is a product of SCIEN CO., LTD (South Korea) The system is based on the results of research (mechanisms of sound absorption / sound insulation) performed by Dr. Lee, representative director of the company and Professor at the Faculty for Automobile Engineering at Ulsan University.

Model 9302 Normal incidence sound absorption ratio measurement system

Determines sound absorption ratio and acoustic impedance related values of sound absorption material (compliant with JIS A 1405-2 and ISO 10534-2)

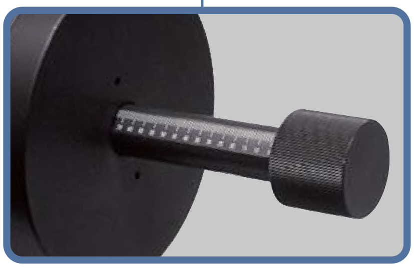
Features
- Compliant with JIS A 1405-2, ISO 10534-2:1998 (Determination of Sound absorption ratio And Impedance In Impedance Tubes — Part 2: Transfer-function Method)
- Transfer function method (2-microphone method) allows instantaneous measurement of sound absorption ratio, reflection coefficient, and surface acoustic impedance
- Transfer function method (2-microphone method) allows instantaneous measurement of surface acoustic impedance, characteristic impedance, propagation constant, equivalent sound speed, and equivalent density. Measurement results are used as input data for transfer matrix method prediction software.
- Optional transfer matrix method prediction software allows prediction of sound absorption ratio and sound transmission loss for layered materials (up to 5 layers)



Low frequency tube (internal diameter 100 mm)
Measurement frequency range 125 Hz to 1600 Hz

High frequency tube (internal diameter 29 mm)
Measurement frequency range 500 Hz to 6300 Hz

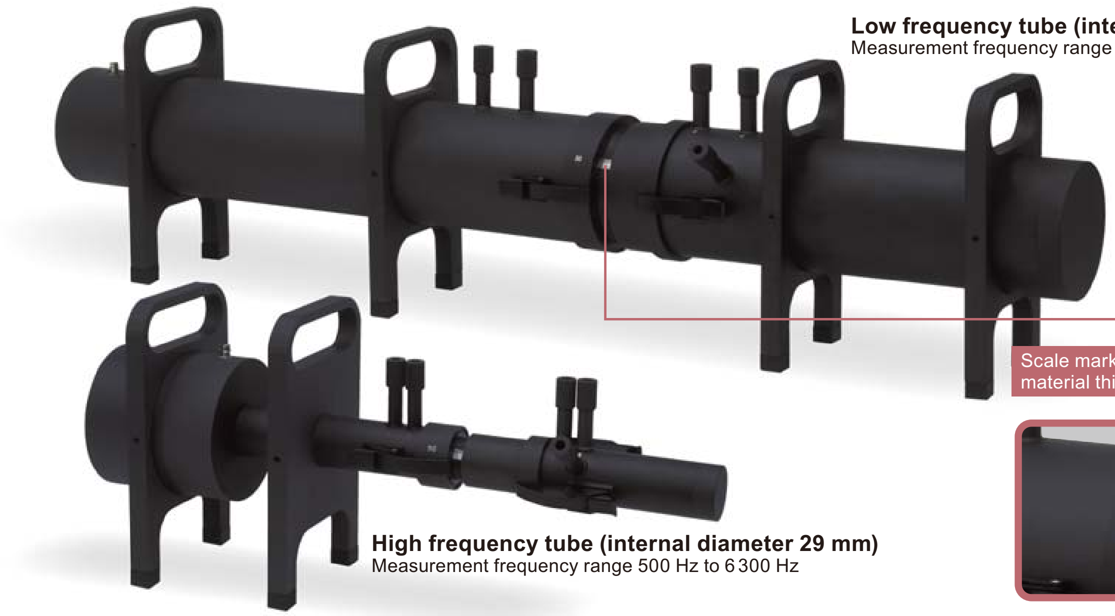
Scale markings used for setting material thickness and air layer depth



Model 9301 Normal incidence sound absorption ratio / Sound transmission loss measurement system

Measures sound absorption ratio and acoustic impedance related values of sound absorption material and normal incidence sound transmission loss of sound insulation material

Features
- Includes all functions of the Model 9302 for sound absorption ratio measurement (See information on Model 9320. Calibration tube is also used for sound transmission loss measurement.)
- Supports instantaneous measurement of sound transmission loss with 4-microphone method
- If sound transmission loss curve comprises resonance characteristics, normal incidence transmission loss estimation software (Option) can be used to estimate the mass law curve



Low frequency tube (internal diameter 100 mm)
Measurement frequency range 125 Hz to 1600 Hz

High frequency tube (internal diameter 29 mm)
Measurement frequency range 500 Hz to 6 300 Hz

Scale markings used for setting material thickness

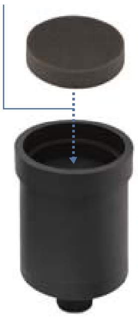
Model 9302

Model 9302 Normal incidence sound absorption ratio measurement system

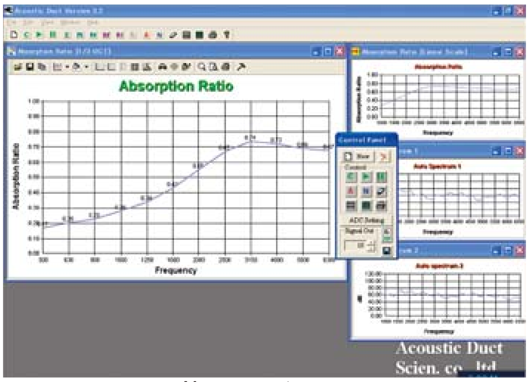
Measurement values and display output

- **Basic function 1 (control panel 1)**
  - Normal incidence sound absorption ratio α
  - Reflection coefficient R (real part / imaginary part)
  - Surface impedance Z_1 (real part / imaginary part, amplitude / phase)
- **Basic function 2 (control panel 2)**
  - Normal incidence sound absorption ratio α
  - Surface impedance Z_1 (real part / imaginary part, amplitude / phase)
  - Characteristic impedance Z_c (real part / imaginary part, amplitude / phase)
  - Propagation constant r (real part / imaginary part, amplitude / phase)
  - Equivalent mass ρ_e (real part / imaginary part) (CSV file format only)
  - Equivalent sound speed C_e (real part / imaginary part) (CSV file format only)
  - Complete data in CSV format (Z_1, Z_c, r, ρ_e, C_e)
- **Main operation steps**
  - Make settings and initiate operations with control panel
  - Set signal output values (speaker input values)
  - Start sound absorption ratio measurement (measurement time approx. 10 seconds)
  - Set depth of back air layer (Air Depth L_{01}, L_{02}, L_{03}) and use T_1, T_2, T_3 switch to start Z_1, Z_c, r measurement (measurement time approx. 20 seconds each)

A piece of material cut to fit the tube diameter is inserted into the tube

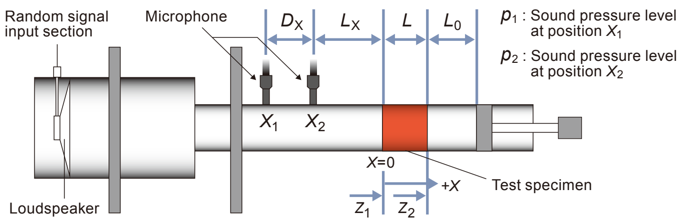


Low frequency tube for measurement



Measurement screen

Internal configuration of tube for normal incidence sound absorption ratio



Measurement principle

The sound emitted from the loudspeaker is absorbed and reflected by the test specimen. Two microphones pick up the incident sound and the reflected sound. Signal processing is performed to calculate the sound absorption ratio and other values according to their respective equations.

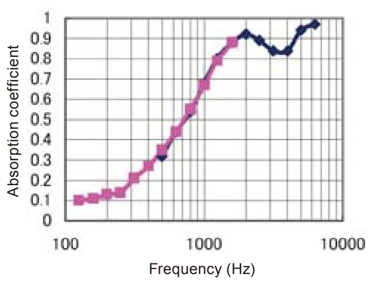
Measurement examples

(Graphs created from text data by spreadsheet software)

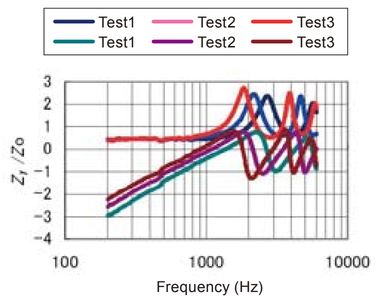
Option Transfer matrix method prediction softwar

············See page 6

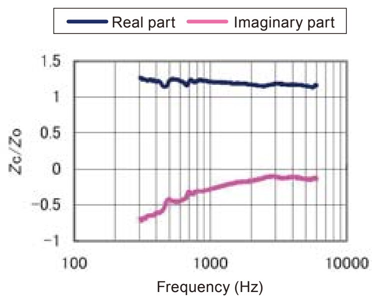
Felt – Sound absorption ratio



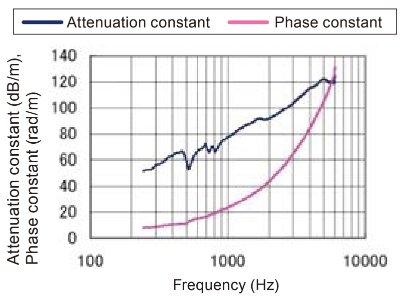
Surface acoustic impedance Z1



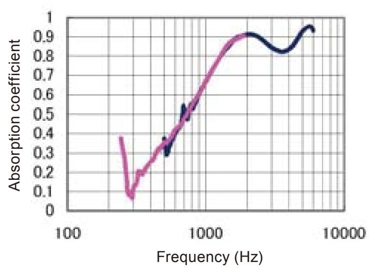
Characteristic impedance Zc



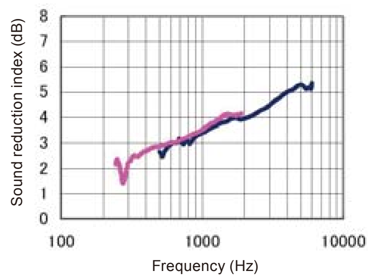
Propagation constant γ



Felt – Normal incidence sound absorption ratio (Option)



Felt – Normal incidence sound transmission loss (Option)



Model
9301

Model 9301*
Normal incidence sound absorption ratio / Sound transmission loss measurement system

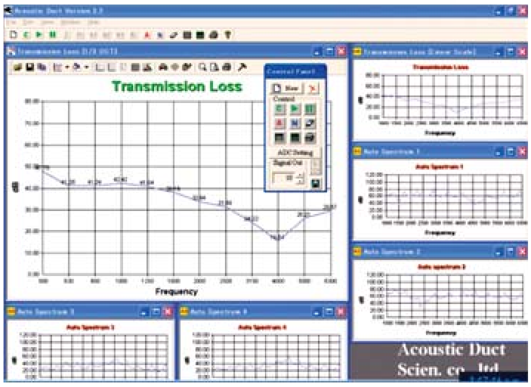
*Includes the functions of the normal incidence sound absorption ratio measurement system (Model 9302)

Measurement values and display output

- **For information on sound absorption ratio and other basic functions, see normal incidence sound absorption ratio measurement system (Model 9302).**
- **Normal incidence sound transmission loss (1/3 octave band analysis, FFT analysis)**
- **FFT analysis of input sound in all channels**

Hold the test specimen in the link tube and fit both ends of the link tube into the main tube with appropriate strength

Link tube (for low frequency measurement)



Measurement screen

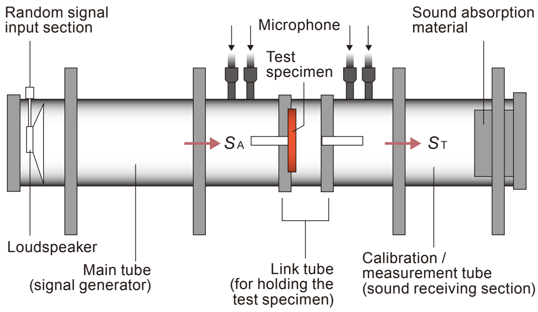
- **Main operation steps**
  - Make settings and initiate operations with control panel
  - Set signal output values
  - Press start switch to initiate sound transmission loss measurement (completes in about 10 seconds)
  - Set up the test specimen in the link tube with suitable strength, and repeat the measurement several times

Measurement principle

Refer to the internal construction diagram of the tube. The intensity I_i of the sound acting on the test specimen (sound insulation material) is measured as the auto spectrum S_A of the incident wave at the two microphones. The intensity I_T of the sound transmitted by the sound receiving tube is measured as the auto spectrum S_T of the incident wave at the two microphones of the calibration / measurement tube. The normal incidence sound transmission loss TL is calculated using the following equation.

$$TL = 10\log_{10}\left[\frac{I_i}{I_T}\right] = 10\log_{10}\left[\frac{S_A}{S_T}\right]$$

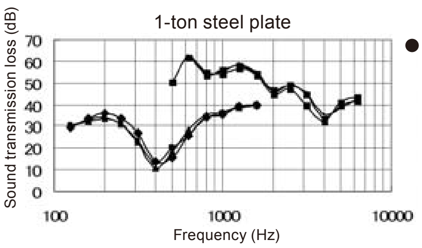
Internal configuration of tube for normal incidence sound transmission loss measurement



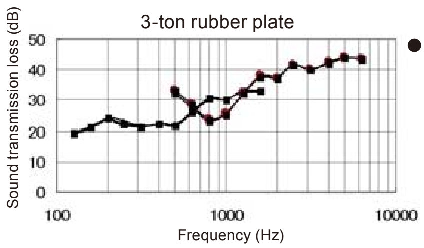
Characteristics of measurement examples
(graphs created from text data by spreadsheet software)

Option Normal incidence transmission loss estimation software (curve fit sheet) ....See page 6

Measurement data (Left: 1-ton steel plate, Right: 3-ton rubber plate)



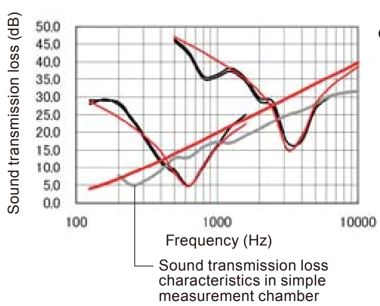
- Example showing resonance characteristics of 1-ton steel plate (sharp resonance frequency exhibited both by low frequency and high frequency tube)



- Example showing resonance characteristics of 3-ton rubber plate (almost no resonance)

* Normal incidence sound transmission loss characteristics (mass law curve) for large test specimen can be evaluated visually.

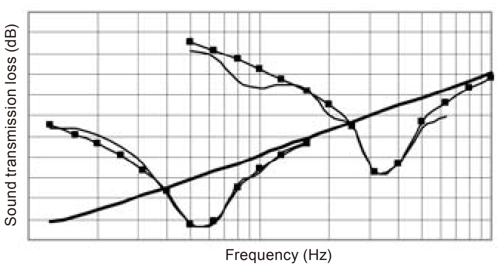
Estimated result for mass law curve (bold red line) (Option)



- Example of estimated mass law curve for 1-ton steel plate (using optional normal incidence transmission loss estimation software)

▮ If the test specimen is made of felt, increasing its thickness by using multiple layers will increase bending stiffness, resulting in resonance characteristics.
▮ If the test specimen is made of lightweight composite resin material, bending stiffness will be high, resulting in sharp resonance characteristics.

Curve fit screen (Option)



- Curve fit diagram using mass law curve

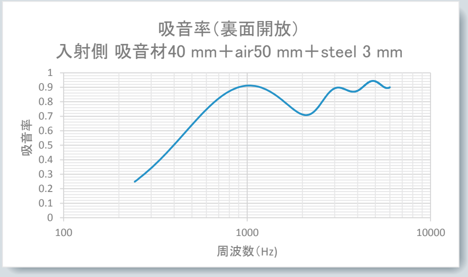
Option

Transfer matrix method prediction software
(for Model 9302 and Model 9301)

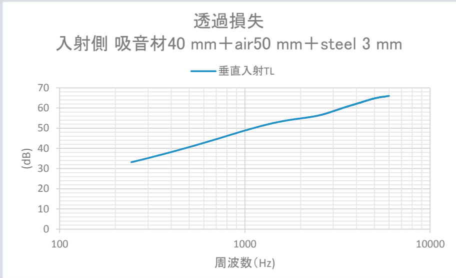
This software program uses worksheet functions of the MS Excel spreadsheet software to perform calculations.
The following calculations are supported.

- Acoustic characteristics of sound absorption material or sound insulation material, using variable parameters such as incidence angle, material thickness etc.
- Total acoustic characteristics for combined material layers

Predictive calculations for sound absorption material are based on CSV data for characteristic impedance Z_c and propagation constant r measured with the Impedance tube. Predictive calculations for sound insulation material are based on sound transmission loss values measured for the panel material or on input data for physical constants.
In order to facilitate predictions for multiple layer configurations, seven types of sheets for single layer predictive calculations are provided, and multiple sheets can be used in parallel for sound absorption material or panel material. As a result, acoustic characteristics of multilayer objects can be checked, and physical parameters such as single layer thickness, surface density, sound incidence angle etc. can be easily varied. During the development of acoustic materials, use of this predictive software is recommended for effectiveness.



Sound absorption ratio



Sound transmission loss

Specifications

Predictive calculation method for Transfer matrix method

Normal incidence, oblique incidence conditions:
Calculation of acoustic characteristics of single layer material and multiple layer composites
Random incidence, co-incidence characteristics:
Calculation of sound transmission loss characteristics of single layer panels
Sound absorption ratio in diffuse sound field (ISO 10534):
Calculation of single layer sound absorption material

Input data

Porous material 1	Characteristic impedance Zc, propagation constant γ, thickness
Porous material 2	Air flow resistance (Delany-Bazley model), thickness
Panel material 1	Sound transmission loss measurement data
Panel material 2	Surface density, Young's modulus, loss factor, Poisson's ratio, thickness
Porous panel	Pore radius, pore spacing, thickness (air layer thickness)
Layer configuration	Max. 10 layers of above materials

Output data

Output content	Graph, numeric data, transfer matrix elements
Output method	Copy & paste of MS Excel sheet output data

Handling of transfer matrix elements

Porous material

Z_c : Characteristic impedance, γ : Propagation constant,
L : thickness, θ_e: Complex angle

$$T=\begin{bmatrix}\cosh(\gamma L\cos\theta_e) & \left(\dfrac{Z_c}{\cos\theta_e}\right)\sinh(\gamma L\cos\theta_e)\\ \left(\dfrac{\cos\theta_e}{Z_c}\right)\sinh(\gamma L\cos\theta_e) & \cosh(\gamma L\cos\theta_e)\end{bmatrix}$$

Panel material

Z_m : Mechanical impedance

$$T=\begin{bmatrix}1 & Z_m\\ 0 & 1\end{bmatrix}$$

Porous panel

k : Wave number, l_e : Equivalent thickness,
ρc : Air resistance, θ_e : Complex angle, P : Aperture ratio

$$T=\begin{bmatrix}\cos(kl_e\cos\theta_e) & \dfrac{j\rho c}{P\cos\theta_e}\sin(kl_e\cos\theta_e)\\ \left(\dfrac{jP\cos\theta_e}{\rho c}\right)\sin(kl_e\cos\theta_e) & \cos(kl_e\cos\theta_e)\end{bmatrix}$$

Option

Normal incidence transmission loss estimation software (for Model 9301)

Many data curves for the normal incidence sound transmission loss of material measured by acoustic tube show resonance characteristics.
The current software uses a sound transmission loss function that can approximate the curve of such data, allowing estimation of the mass law curve for the sound transmission loss of large-size materials.


Manipulation sheet for sound transmission loss function

Calculation method

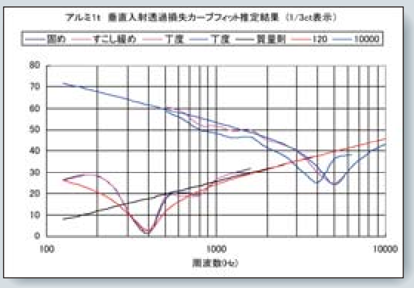
Curve fit operation (variable manipulation) of sound transmission loss TL function

Input data

Measurement data for normal incidence sound transmission loss level.
(low frequency, high frequency)

Output data

Curve fit data (125 Hz to 10 000 Hz, 1/3 octave bands)
Mass law data for acoustic equivalent surface density


Output data

Approximation function for sound transmission loss TL (Acoustic characteristics of flat panel)

$$TL=10\log_{10}\left[\frac{p_i}{p_t}\right]^2=10\log_{10}\left\{\left[1+\frac{r}{2\rho c}\right]^2+\left[\frac{1}{2\rho c}\right]^2\left[\omega m-\frac{k}{\omega}\right]^2\right\}$$

(m: Surface density, r: Resistance coefficient, k: Spring constant,
ρc: Acoustic impedance density of air, Resonant angular frequency = $2\pi f$)

■ Specifications

Tube Model 9302 Sound absorption ratio measurement System

Standard compliance JIS A 1405-2, ISO 10534-2:1998

	Tube name	Dia. (mm)	Length (mm)
Low frequency measurement range 1/3 oct (125 Hz to 1 600 Hz)	Main section	100	645 (620)*
	Calibration section	100	215
	Measurement section	100	210 to 313
High frequency measurement range 1/3 oct (500 Hz to 6300 Hz)	Main section	29	345 (320)*
	Calibration section	29	215
	Measurement section	29	210 to 313

*Linked length

- Main tube comprises integrated speakers
- Calibration tube comprises internal sound absorption material
- Two dummy microphones (plastic) supplied
- Test specimen diameter: 100 mm and 29 mm (nominal value)
- Test specimen thickness + back air layer: 100 mm max. (both for low frequency and high frequency system)
- Maximum external dimensions when assembled
  Model 9302 For low frequency measurement 280 (H) × 150 (W) × 930 (D) mm
  For high frequency measurement 280 (H) × 180 (W) × 640 (D) mm
- Test specimen supplied with system: 1 each

Result display (Model 9302)

Sound absorption ratio	1/3 octave band analysis, FFT analysis display
Acoustic impedance Z	Absolute value, Phase, Real part, Imaginary part
Reflection coefficient	Absolute value, Phase, Real part, Imaginary part
Surface impedance Z_1	Absolute value, Phase, Real part, Imaginary part
Characteristic impedance Z_C	Absolute value, Phase, Real part, Imaginary part
Propagation constant r	Attenuation constant α, Phase constant β
CSV format file output	Density p, Sound velocity c, Z_1, Z_C , r

Tube Model 9301* Sound absorption ratio / Sound transmission loss measurement system

*Includes the functions of the normal incidence sound absorption ratio measurement system (Model 9302)

	Tube name	Dia. (mm)	Length (mm)
Low frequency measurement range 1/3 oct (125 Hz to 1600 Hz)	Main section	100	645 (620)*
	Link section	100 (108)	96 to 116
	Calibration / Measurement section	100	400 (390)*
	Sound absorption ratio measurement section	100	210
High frequency measurement range 1/3 oct (500 Hz to 6300 Hz)	Main section	29	345 (325)*
	Link section	29 (36)	116 to 156
	Calibration / Measurement section	29	169 (159)*
	Sound absorption ratio measurement section	29	210 to 313

*Linked length

- Main tube comprises integrated speakers
- Calibration / measurement tube comprises internal sound absorption material
- Three dummy microphones (plastic) supplied
- Test specimen diameter: sound absorption ratio measurement 100 mm and 29 mm, sound transmission loss measurement 108 mm and 36 mm (nominal value)
- Sound transmission loss test specimen thickness: 20 mm max. for low frequency system, 40 mm max. for high frequency system
- Sound absorption ratio test specimen thickness + back air layer: 100 mm max. (both for low frequency and high frequency system)
- Maximum external dimensions when assembled
  Model 9301 For low frequency measurement 280 (H) × 150 (W) × 1130 (D) mm
  For high frequency measurement 280 (H) × 180 (W) × 640 (D) mm
- Test specimen supplied with system: 1 each

Result display (Model 9301)

Sound absorption ratio	1/3 octave band analysis, FFT analysis display
Acoustic impedance Z	Absolute value, Phase, Real part, Imaginary part
Reflection coefficient	Absolute value, Phase, Real part, Imaginary part
Surface impedance Z_1	Absolute value, Phase, Real part, Imaginary part
Characteristic impedance Z_C	Absolute value, Phase, Real part, Imaginary part
Propagation constant r	Attenuation constant α, Phase constant β
CSV format file output	Density p, Sound velocity c, Z_1, Z_C, r
Sound transmission loss	1/3 octave band analysis, FFT analysis display

● Real time data analysis and display

FFT analysis frequency range (upper limit is effective range)	Low frequencies (6 Hz to 1 900 Hz) High frequencies (6 Hz to 6 497 Hz)
Auto spectrum	Microphone input waveform spectrum analysis and display (Model 9302: 2-channel data, Model 9301: 4-channel data)
Transfer function	Absolute phase data analysis and display

● Microphone

Nominal diameter	1/4 inch
Frequency range	20 Hz to 15 kHz : ±3 dB 100 Hz to 10 kHz : ±1 dB
Sensitivity	50 mV/Pa ±5 %
Maximum sound pressure level	124 dB
Temperature range	−10 °C to +50 °C
Output terminal	BNC
Residual noise	FLAT (20 Hz to 20 kHz) <100 μV A-weight<30 μV
Number of microphones	2 (Model 9302), 4 (Model 9301)
BNC-BNC cable	1 set (2 parallel cables) (Model 9302) 2 sets (2 parallel cables) (Model 9301)

● Amplifier

Chassis dimensions	30 mm (H) × 100 mm(W) × 160 mm (D)
Input connectors (for microphones)	4 channels, BNC connectors CCLD (Constant Current Linear Drive) compliant current supply (24 V, 2.1 mA to 2.5 mA)
Output terminal (for loudspeaker)	1 channel, BNC connector
Input voltage range (settable by software, RMS)	100 mV, 1 V, 10 V +20 dB, 0 dB, −10 dB
Gain tolerance	±0.1 dB
Channel-to-channel gain error	±0.1 dB
A/D conversion resolution	24 bits
Sampling rate	48 kHz/ch
Dynamic range	128 dB
Frequency response (flat response)	0.5 Hz to 21 kHz (within 0.2 dB) 1 Hz to 20 kHz (within 0.05 dB)
THD	0.007 % (typ.)
Output voltage (for loudspeaker, RMS)	1.0 V
Output frequency range	0.5 Hz to 22 kHz
Signal output type	White noise
USB interface connector	USB1.1 / USB2.0
Power requirements	Supplied by USB terminal from computer (max. 500 mA)
Loudspeaker cable	BNC-BNC cable x 1
USB cable	USB connector cable x 1

● Options

Computer (recommended operation environment)	
CPU	2 GHz or higher
RAM	512 MB or more
HDD	10 GB (free space)
USB	USB 1.1 / USB 2.0
Supported operating systems	Microsoft Windows 7 Professional 32 bit / 64 bit, 10 Pro 64 bit

Transfer matrix method prediction software	For Model 9302 and Model 9301
Normal incidence transmission loss estimation software	For Model 9301

Related Product

Model 9303 Pavement sound absorption ratio measurement system

Measurement of noise emitted by road vehicles requires a standard test track as specified in ISO 10844 (JIS D 8301). The test method for in situ measurement of the sound absorption ratio is specified by ISO 13472-2:2010.
This measurement system complies with these requirements.
By simply placing the Impedance tube on the track surface, the sound absorption ratio can be measured quickly, making the system optimal for measurements during construction of a standard track, as well as for aging measurements.

Principle of normal incidence sound absorption ratio measurement system

● Result output and display ● Internal calculation or definition

Sound pressure (p)=Incident sound pressure (p_i) + Reflected sound pressure (p_r)
Particle velocity of sound (u) = Incidence rate (u_i) + Reflection speed (u_r)
Material transmitted sound: Sound pressure (p_t), Particle velocity (u_t)

● Transfer function after calibration

$$H_{12} = \hat{H}_{12} / H_C \qquad \hat{H}_{12} = \frac{p_2}{p_1} = \frac{e^{jk_0 L_X} + R e^{-jk_0 L_X}}{e^{jk_0(L_X+D_X)} + R e^{-jk_0(L_X+D_X)}} = \hat{H}_{12r} + j\hat{H}_{12i}$$

● Reflection coefficient
Reflection coefficient at reference surface (x=0)

$$R = \frac{p_r}{p_i} = \frac{H_{12} - e^{-jk_0 D_X}}{e^{jk_0 D_X} - H_{12}} e^{2jk_0(L_X+D_X)} = R_r + jR_i$$

● Absorption coefficient
Ratio of incident sound power and transmission quantity

$$\alpha = \frac{p_t^2}{p_i^2} = \frac{p_i^2 - p_r^2}{p_i^2} = 1 - |R|^2$$

● Normalized surface acoustic impedance
Material surface
Acoustic impedance (∗: with rigid termination)

$$Z_n = \frac{p}{u} \times \frac{1}{Z_0} = \frac{Z}{Z_0} = \frac{1+R}{1-R} = Z_{nr} + jZ_{ni}$$

● Material transmitted sound expression
Can be expressed by wave number k_m and propagation constant $r = \alpha + j\beta$
● Wave number

$$p_t = p_{t}e^{-jk_m x} = p_{t}e^{-\gamma x}、\quad jk_m = \alpha + j\beta、\quad k_m = \omega / c_e$$

$$k = \omega / c = 2\pi f / c、$$ f : Frequency c : Sound velocity (20 °C 343 m)

● Normalized surface acoustic impedance
Impedance as seen from material surface (x = 0) to material, with back air layer L_{01} (L_{02}, L_{03}).
Used for calculating Z_{cn} and r.

$$Z_{1n} = \frac{Z_1}{Z_0} = j\frac{-H_{12}\sin(kL_X) + \sin\{k(L_X+D_X)\}}{H_{12}\cos(kL_X) - \cos\{k(L_X+D_X)\}} = Z_{1r} + jZ_{1i}$$

● Normalized rear surface acoustic impedance
as seen from material rear surface (x = L) to rigid termination, with back air layer L_{01} (L_{02}, L_{03}).
Used for calculating Z_{cn} and r.

$$Z_{2n} = \frac{Z_2}{Z_0} = -j\cot(kL_0)$$

● Normalized characteristic impedance
Characteristic impedance for sound in material, with back air layer [L_{01}, L_{02}] ([L_{02}, L_{03}] [L_{03}, L_{01}])

$$Z_{cn} = \frac{Z_c}{Z_0} = \pm\sqrt{\frac{Z_1 Z'_1(Z_2 - Z'_2) - Z_2 Z'_2(Z_1 - Z'_1)}{(Z_2 - Z'_2) - (Z_1 - Z'_1)}} = Z_{cnr} + jZ_{cni}$$

● Propagation constant
Expresses the attenuation and phase velocity of sound traveling in the material

$$\gamma = \frac{1}{2L}\log_e\left[\frac{Z_1+Z_c}{Z_1-Z_c} \times \frac{Z_2-Z_c}{Z_2+Z_c}\right] = \alpha\,[\mathrm{nep/m}] + j\beta\,[\mathrm{rad/m}]$$ ∗Note 1

$$= 8.686\alpha\,[\mathrm{dB/m}] + j\beta\,[\mathrm{rad/m}]$$ ∗Note 2

● Equivalent sound speed
Calculated from material transmitted sound expression. C_e [m/s]

$$c_e = \frac{2\pi f\beta + j2\pi f\alpha}{\alpha^2 + \beta^2} = c_{er} + jc_{ei}$$ ∗Note 1

● Equivalent density
Calculated from material characteristic impedance Z_C and equivalent sound speed C_e.
($Z_C = \rho_e C_e$ applies)
ρ_e [kg/m³]

$$\rho_e = \frac{Z_c}{c_e} = \rho_{er} + j\rho_{ei}$$ ∗Note 1

Reference items for measurement principle (See page 4)

- D_X, L_X, L, L_0, X_1, X_2, X : [m]
- Suffix r, i: real part, imaginary part
- Normalized impedance: Divided by air characteristic impedance Z_0 ($Z_0 = \rho c$ = 415 [N・s/m³], at 20 °C)
- ∗:Termination for back air layer is same as Z_{1n}
- Z_{1n}, Z_{cn}, r obtain values corresponding to the respective back air layers L_{01}, L_{02}, L_{03} and average values (Z_{cn}, r).
- C_e, ρ_e are average values

∗Note 1: Only CSV format complete data are shown ∗Note 2: Only display data are shown

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