PULSE™ Material Testing is a complete and fully integrated system for making acoustic measurements on small material samples in the 50 Hz to 6.4 kHz frequency range. The system consists of PULSE Material Testing Program Type 7758, Impedance Tube Kit (50 Hz – 6.4 kHz) Type 4206 or Impedance Tube Kit (100 Hz – 3.2 kHz) Type 4206A, Power Amplifier Type 2716 C and PULSE, the Multi-analyzer System Type 3560.

**USES**
- Measurement of:
  - acoustic absorption coefficient
  - acoustic reflection coefficient
  - normalised impedance
  - normalised admittance
- Measurements on complex or composite materials
- Measurements on orientation-sensitive materials
- Simulation of measurements on hanging ceilings

**FEATURES**
- Microsoft® Windows® based PULSE platform ensures speed and exceptional accuracy
- Intuitive, task-oriented user-interface simplifies the entire measurement process from setup to documentation of final results
- Seamless combination of measurements made with various tubes allows use of a large frequency range (50 Hz to 6.4 kHz)
- Averaging of results from different measurements allows compensation for sample variations and simulation of composite materials
- Batch support ensures easy setup and execution of groups of measurements
- Extraction of 1/n-octave centre frequency information enables comparison with data obtained using the standing wave ratio method
- Integration with Microsoft® Word and Excel supports fast, automated reporting and advanced post-processing
- On-line, context-sensitive help ensures quick mastery of the software
- Support of custom measurement tubes or tubes from other vendors allows use of existing equipment

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**Introduction**

**Acoustic Material Testing**

With the growing interest in noise-control issues and the increasing importance of sound quality as an important aspect of product design, acoustic material testing is quickly gaining in significance.

Software simulation now plays an important role in predicting the impact of noise-control materials in product development but its accuracy depends on the accurate specification of the acoustic characteristics of the product’s materials. To this end, acoustic material testing is the process by which the acoustic characteristics of materials are determined in terms of absorption, reflection, impedance, admittance and transmission loss.

Brüel & Kjær offers a complete range of tubes for acoustic material testing measurements, such as the sound absorption coefficient, reflection coefficient, acoustic impedance and admittance, and transmission loss coefficient.

Impedance Measurement Tube Type 4206 and Impedance Measurement Tube for ASTM Type 4206 A use a two-microphone method to measure the acoustic parameters of small test samples. Transmission Loss Tube Type 4206 T uses a four-microphone transfer-function method. The Type 4206 family of measurement tubes complies with international standards and can form part of a complete, acoustic, material-testing system featuring PULSE™, Brüel & Kjær’s real-time, multi-analysis system.
Two-microphone Impedance Measurement Tubes

Two-microphone Impedance Measurement Tube Type 4206 and Impedance Measurement Tube for ASTM Type 4206A are used to measure the acoustic parameters of small test samples including absorption coefficient, reflection coefficient and normalised impedance, in the frequency ranges from 50 Hz to 6.4 kHz and 100 Hz to 3.2 kHz, respectively. This is achieved by measuring the incident and reflected components of random or pseudo-random noise, which are generated inside the impedance tube by the sound source. The reflected component is affected by the acoustic properties of the sample under test.

**Fig. 1.1**
Two-microphone Impedance Measurement Tube Type 4206 (optional medium measurement tube not shown)

**Type 4206**

Two Microphone Impedance Measurement Tube Type 4206 consists of:

- a large (low-frequency) measurement tube that has a frequency-weighting unit and sound source mounted at one end, and three couplers for mounting microphones flush with the inside of the tube
- an optional medium (mid-frequency) measurement tube UA 2033 that has three microphone couplers and is mounted directly onto the open end of the large measurement tube. This tube is designed to meet the ASTM E1050—98 (American Society for Testing and Materials) code in the USA
- a small (high-frequency) measurement tube that has two microphone couplers and is mounted directly onto the open end of the large measurement tube
- large, medium (optional) and small sample holders, each with an acoustically hard backplate attached to a sliding piston
- two extension tubes that can be fitted between the measurement tube and sample holder to increase the length of either of the measurement setups

These components can be assembled into standard large, medium and small tube setups into which the test samples are mounted. The effective length of each setup can be changed by fitting one or both extension tubes and by changing the position of the sliding piston inside the sample holder.
Impedance Measurement Tube for ASTM Type 4206 A consists of:

- a large tube that has a frequency-weighting unit and sound source mounted at one end, and three couplers for mounting microphones flush with the inside of the tube
- a medium (mid-frequency) measurement tube UA 2033 that has three microphone couplers and a medium sample holder, and which is mounted directly onto the open end of the large measurement tube. This tube is designed to meet the ASTM E1050–98 (American Society for Testing and Materials) code in the USA

General

Three types of weighting are selectable with the large tube’s frequency weighting unit:

- high-pass, for high-frequency measurements in the small tube
- linear, for measurements in the large tube
- low-pass for extra measurement accuracy below 100 Hz

Measurements inside the tube are made with two 1/4" Condenser Microphones Type 4187 that are supplied with Types 4206 and 4206 A, and which are specially designed to reduce errors due to pressure leakage at high frequencies.

Fig. 2.1
Evolution diagram of Impedance Measurement Tubes
Making and Mounting Test Samples

The shape and size of the test samples is critical to the accuracy of the measurements. Therefore, you must take great care when preparing and mounting your test samples. The following guidelines must be followed when cutting and mounting each test sample:

1) Cut each sample so that it fits snugly into the sample holder:
   - 100 mm (3.94 inch) diameter for large tube samples
   - 63.5 mm (2.50 inch) diameter for medium tube samples
   - 29 mm (1.14 inch) diameter for small tube samples
   with the surface of the sample as flat as possible. If the sample is too tight, it will bulge in the centre; if it is too loose, there will be a space between the edge of the sample and the sample holder.

2) If the test material is not uniform, cut a minimum of two samples that are representative of the overall texture of the material. The results from a number of tests with different samples can be averaged to give a better estimate of the acoustic properties of the material.

3) If the back of the sample is uneven, a layer of modelling clay (or something similar) can be placed between the sample and the piston disk, so that there is no air gap between them (see Fig. 4.4a). This does not apply if you are mounting a sample as in step 5.

4) Mount the sample so that the outer face is perpendicular to the axis of the tube.

5) To simulate measurements on hanging ceilings (or similar situations), draw the piston out behind the test sample to create an air gap of measurable length. This length is the distance from the front of the test sample to the front of the piston disk, and can be read directly from the graduations on the piston rod. If you are using extension tubes, add 200 mm to the reading from the rod for each extension tube used. In this type of measurement, modelling clay should not be used in mounting the sample (see step 3).

6) *Add air gap width to the sample width, which is directly read off piston.

6) If the sample you wish to test is orientation-sensitive (for example, foam insulation beads), you can mount the impedance tube vertically using the mounting holes on the large measurement tube foot, so that the sample remains horizontal (see Fig. 4.4b). The tube can be wall-mounted using two ordinary screws. These screws should have a head diameter between 6 and 11 mm, and a stem diameter less than 6 mm. The screws must be positioned in a horizontal plain 74 mm apart with the screw heads not less than 2 mm above the surface of the wall.

7) If the sample to be tested consists of absorbent material with a hard surface covering plate (such as acoustic tiling), mount the sample as shown in Fig. 4.4c, so that the hard covering plate fits the external diameter of the measurement tube, and the soft backing fits into the sample holder as described in steps 1 to 4.

To mount a sample in this way, you must reposition the adjustable foot so that the sample is held securely in place between the measurement tube and the sample holder with the securing clips locked. For example, if the hard layer of the test sample is 20 mm thick (the maximum possible thickness for this type of mounting), move the adjustable foot 20 mm closer to the open end of the measurement tube and secure it there by tightening the screw. When mounting samples in this way, it is recommended that you smear Vaseline (or something similar) onto the outside of the open end of the measurement tube so that there is an air-tight seal between the measurement tube and the sample holder.
Fig. 4.4 Three examples of correctly mounted test samples:

a) An uneven sample mounted with modelling clay

b) A composite orientation-sensitive sample mounted horizontally with the tube mounted vertically and the sample holder piston withdrawn to simulate hanging-ceiling measurements

c) A composite sample with a hard surface and soft backing, mounted to fit the exterior diameter of the large measurement tube

Impedance-tube setup for PULSE

Now to operate the PULSE software ....
Pulse labshop opens with the Project Setup page including Material Testing Explorer which contains all the previously measured results.
After checking the parameters on the various tabbed pages of the Material Testing Control shield... Connect Signals.

Brings up Configuration Organiser and Measurement Organiser.
For the Large Tube (Input 3 and 4) ... Select Transducer ...  

Brings up Database Administrator shield. ... Press the Find button  
Brings up Find Transducer shield with recognised microphones (put in earlier)
Select Mic A s/n 2557573 for Input 3 and Mic B s/n 2557574 for Input 4
Put in Reference Sample in the Reference position 25 mm retraction of plunger to accommodate the 25 mm foam samples supplied with the system. The sample width is directly read off the graduations on the plunger

MUST HAVE A SAMPLE IN THE TUBE FOR CALIBRATION

The Manual describes the Two Microphone Method of measuring the acoustic absorption and the Calibration Method

See next pages for Theory of Operation and Calibration
The Two-microphone Method

The two-microphone method of measuring the acoustic 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 (see Fig. 1.3).

**Fig. 1.3** Cut-away diagram of the impedance measurement tube, showing the incident and reflected components of the stationary-random signal

From the incident and reflected components of the sound pressure at the two microphone positions, three frequency response functions are calculated: $H_i$, the frequency response function; $H_r$, the frequency response function associated with the incident component; and $H_{ir}$, the frequency response function associated with the reflected component. Using these values, the complex reflection coefficient ($R$) is calculated from the following equation:

$$R = \frac{(H_i - H_{ir})}{(H_r - H_i)} e^{i2k(l + s)}$$  \hspace{1cm} (1)

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

Using this value for the reflection coefficient, the normalised impedance ratio ($\frac{\varepsilon}{\rho c}$) and the sound absorption coefficient ($\alpha$) can be calculated from the following equations:

$$\frac{\varepsilon}{\rho c} = \frac{1 + R}{1 - R}$$  \hspace{1cm} (2)

$$\alpha = 1 - |R|^2$$  \hspace{1cm} (3)

The two-microphone theory assumes plane-wave propagation, no mean flow and no losses due to absorption at the tube wall. The design of the Type 4187 protection grid and the microphone positions assures that the absorption at the tube wall of the Two-microphone Impedance Measurement Tube is kept to a minimum.
The Calibration Method

As described above, the frequency response function is calculated from the cross-spectrum of the two microphone signals. Therefore, any phase or amplitude mismatch between these microphone channels will corrupt its calculated value. During the calibration procedure, the frequency response function is calculated with the two microphones interchanged, and then again in their initial positions. The geometric mean of these two results is a complex value that can be "added" to any subsequent frequency response function that is calculated using the same setup, effectively eliminating errors due to any mismatches in the microphone channels.

During the calibration procedure, the calibration frequency response functions for the microphones in the standard positions \( H_{C1} \) and the interchanged positions \( H_{C2} \) are calculated as:

\[
H_{C1} = |H_{C1}|e^{j\phi_1}
\]  
and

\[
H_{C2} = |H_{C2}|e^{j\phi_2}
\]

where \( \phi_1 \) is the phase of the calibration frequency response function \( H_{C1} \), \( \phi_2 \) is the phase of the calibration frequency response function \( H_{C2} \) and \( j \) is \( \sqrt{-1} \).

From these values, the calibration factor \( (H_c) \) is calculated as:

\[
H_c = \frac{|H_c|e^{j\phi_c}}{|H_{C1}|}
\]

where:

\[
|H_c| = \sqrt{|H_{C1}|^2 + |H_{C2}|^2}
\]

\[
\phi_c = \frac{1}{2}(\phi_1 + \phi_2)
\]

This calibration factor can now be "added" to any frequency response function that is calculated using the tube setup, giving a value that is unaffected by amplitude or phase mismatches between the microphone channels.

For example, the following frequency response function is measured, with the microphones in the standard positions:

\[
H = |H|e^{j\phi}
\]

The correction factor is "added", giving the corrected frequency response function \( (H_1) \):

\[
H_1 = \frac{H}{H_c} = |H_1|e^{j\phi_h}
\]

where:

\[
|H_1| = \frac{|H|}{|H_c|}
\]

\[
\phi_h = \phi - \phi_c
\]

This frequency response function \( H_1 \) is the value that is used to calculate the acoustic properties of the test sample.

During the calibration procedure, a sample must be mounted in the sample holder. A calibration sample with as high an absorption as possible in the frequency range of interest should be chosen.

Calibration samples are provided with Brüel & Kjær impedance tubes. These are general-purpose calibration samples with a broadband frequency attenuation that provides high positioning tolerances and long-term stability. The absorption, however, is not very high so, for special, low-absorption cases, a dedicated calibration sample should be considered that has higher absorption in the frequency range of interest. Although the sample used for calibration is called the calibration sample, the measurement is not traceable through the calibration sample.
Select Calibration from the Task List

Click Calibrator and select Calibrator Type then OK  (4231)

Clicking the View Button brings up FFT monitor
Put Microphone A into the Calibrator 4231 with 1/4” reducer. Turn on Calibrator. Press the Start Button in Calibration Master Shield Pulse will calibrate Mic A and wait for Mic B. Program will detect Microphone change.

If microphone is not identified by the system it will bring up a message dialogue box Find the transducer and put it into the Hardware Set up

Select the All Tab of the Hardware Set Up and select the Transducer Serial Number
Calibrates Mic A - Remove A and place B into the calibrator

---

Measurement calibrated

-- Measurement Channel Data --
Frame: IDAe Frame Type 35608 (frame 1)
Module: 5/1 ch. I/O Controller Module Type 7639 (slot 1)
Signal: Signal A
Transducer: Mic A
Gain adjust: 1.000 (0.00 dB)

---

Searching Signal Input...

---

Searching for the following Calibrator(s):

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<thead>
<tr>
<th>Type</th>
<th>Frequency</th>
<th>Level</th>
<th>Deviation</th>
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<tr>
<td>Type 4231</td>
<td>1000.0</td>
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<td>5.0 dB</td>
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---

Measuring

-- Measurement Channel Data --
Frame: IDAe Frame Type 35608 (frame 1)
Module: 5/1 ch. I/O Controller Module Type 7639 (slot 1)
Signal: Signal B
Transducer: Mic B
Gain adjust: 1.000 (0.00 dB)
Gains are adjusted and recorded in the Hardware Set Up Database.

Stop Calibration  Move to Signal to Noise Ratio on the Task List
Measure Background Noise

Switch to signal Measurement and click Start
Inputs flash Yellow and Red while the system Auto-ranges
Program stops automatically

Move to Transfer Function Calibration on the Task List

Interchange Microphone Positions first so as not to disturb them after the final measurement
Change Microphones back to Normal position and Start again after selecting in Calibration Control Shield.

Ready to measure. Go to Measurement on the Task List
Distinguish each measurement with a descriptive file name

Name a file and add to list

I called the file Cal-17-6-09 to describe what it is and when done
Note the software depicts it as being the Large Tube as the Small Tube has it’s own set up
Click Start Button and measure Absorption Coefficient from 50 Hz to 1600 Hz (Can vary the range of the tube measurement frequencies and the overlap frequencies)

Results Page set up below
Go back to set up and choose small tube

May have to reconnect and re-find the microphones as shown before

Notice the Background Noise graph spans to 6.4 KHz
Calibrated with test sample rather than calibration sample as below

Large discrepancy from expected Transfer Function

Recommended to use calibration sample (known).
Measured sample calibrated from itself gives same answer.
Recalibration using standard calibration sample

Calibration Large and Small Calibration sample
Combined for Large and Small for Calibration sample

Measured sample
Move down Task List to Post Processing
Combination TAB allows combination of Large and Small tube measurements.
Select Large and Small from appropriate column - Select overlap range - Low f and High f

Averaging TAB allows averaging of selected samples - Small, Large or Combined
Extraction TAB allows files to be listed in the window from the Material Testing Explorer Search selection by description in the TUBE window.

Fractional Octave Band Results.

Using the FREQUENCIES box results can be shown in Octave, 1/3 Octave, 1/12 Octave and 1/24 Octave band centre bands.

The standard NRC Rating figures can be extrapolated from the data this way. ie 250 Hz, 500 Hz, 1000 Hz and 2000 Hz. Averaged for a single NRC figure

The Graph selected to represent the results can be changed to CPB, Logarithmic and Curve It can also be varied to Bar, Line, Waterfall and incorporate Overlays.

Data is copied off the Graph by selecting COPY ACTIVE CURVE off a right click after selection with the left click. (see page 31)

I have made some templates in EXCEL to accept the data
Template Full Range 4206.xls - For full range Has three 'copy to' pages - Copy Combined Data to Graph - 3201 lines of data 0 - 6.4 KHz
- Copy Large Tube Data - 801 lines of data 0 - 1.6 KHz
- Copy Small Tube Data - 801 lines of data 0 - 6.4 KHz

Data can be copied into a NOTEPAD file and named and saved Copying returns 3 columns: - Number, Frequency and Absorption Co-efficient result Other information such as Centre Frequency and Date and Time will be in the header
The Results TAB allows selection of results of ... Absorption Coefficient, Reflection Coefficient, Impedance Ratio, Admittance Ratio and Corrected Transfer Function

When Results box is ticked the graph of the selected measurement in the extraction list is displayed. To remove a stubborn residual graph, Right click CHECK ALL in the EXTRACTION field then CHECK NONE. Go back to RESULTS TAB and click the graph selection off then on. The graph should now be clear.
Header Size: 78
Pulse Version: 42
Decimal Symbol: .
Date Format: dd/MM/yyyy
Time Format: HH:mm:ss:mmm
Data Type: Real
Slice: False
Z-Axis type: Linear
Z-Axis size: 1
Z-Axis unit:
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Z-Axis delta: 1.0000000000e+000
X-Axis type: Linear
X-Axis size: 3201
X-Axis unit: Hz
X-Axis first value: 0.0000000000e+000
X-Axis delta: 2.0000000000e+000
AcousticWeighting: None
AmplitudeUnit:
Analyzer: FFT_Spectrum_Averaging
AnalyzerName: FFT Analyzer

CenterFrequency: 8.0000000000e+002

Coordinate: Real
dBReference: 1.0000000000e+000
Header Size: 78
Pulse Version: 42
Decimal Symbol: .
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X-Axis size: 3201
X-Axis unit: Hz
X-Axis first value: 0.0000000000e+000
X-Axis delta: 2.0000000000e+000
AcousticWeighting: None
AmplitudeUnit:
Analyzer: FFT_Spectrum_Averaging
AnalyzerName: FFT Analyzer

CenterFrequency: 8.0000000000e+002

Coordinate: Real
dBReference: 1.0000000000e+000

Domain: 1
Function: Frequency Response

jwWeighting: None
MultiBufferName: Input
NBW: 1.5000000000e+000

OverlapFailed: False
Overrun: False
Power: False

Ratio: True
RecordLength: 5.0000000000e-001
ReducedSize: True
Ref_Signal: Signal A

RefSignalUnit: Pa

Signal: Signal B

SignalUnit: Pa
SpectralUnit: RMS

Title: Absorption Coefficient (Jun2e42009smallKenCal, Combined - C)
Title1: June42009KenCal combined with Jun2e42009smallKenCal
Z-index: 1
Date: 12/06/2009
Time: 13:16:23.999
Relative time: 0.00000e+000
Z-axis: 0.0000000000e+000
1 0.0000000000e+000 0.000000e+000
2 2.0000000000e+000 1.14807e-001
3 4.0000000000e+000 -1.00277e+000
4 6.0000000000e+000 -3.68003e+001
5 8.0000000000e+000 -5.23799e-001
6 1.0000000000e+001 -1.13906e+000
7 1.2000000000e+001 -6.13511e-001
8 1.4000000000e+001 3.50440e-001
9 1.6000000000e+001 -1.15738e-003
10 1.8000000000e+01 1.43900e-001
11 2.0000000000e+01 3.66966e-002
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17 3.2000000000e+01 -1.31988e-001
18 3.4000000000e+01 -5.69388e-003
19 3.6000000000e+01 -1.01453e-002
20 3.8000000000e+01 -9.67649e-002

(21 - 3185 not shown)

Last part of information after the data

TagsBegin:
OverLoad: False
TagsEnd:
TagScalesBegin:
TagScalesEnd:

*** Cursor Reading: Cursor Values
Y = 0.522
X = 2.258 kHz

*** Cursor Reading: Status
12/06/2009 13:16:23.999

*** Cursor Reading: Maximum Value
Y = 0.683
X = 4.088 kHz

*** Cursor Reading: Minimum Value
Y = -36.8
X = 6.000 Hz
### Page 34

#### Copy Combined Data to Graph

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To access 1/3 Octave results - AVERAGING TAB list in the Material Testing Control shield.

Right click on the graph.
Copy Active Curve to Notepad

16 Hz to 6.4 KHz range

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</table>
Right Click Properties and bring up graph properties shield

On FUNCTION TAB change GRAPH TYPE to BAR

On X-AXIS TAB select CPB
- The x-axis is scaled around the 1/3 Octave Centre frequencies

Page 36
On X-AXIS TAB select Logarithmic
The x-axis is scaled Logarithmically around the 1/3 Octave Centre Frequencies
Select Fill Curve from Options 2 TAB to fill curve as below

You can step down the Task List to Excel Export, select the files and press Export

An Excel file is created from the selected file and has 3 Tabbed sheets of information Absorption Coefficient, Project Set Up and Measurement Properties
<table>
<thead>
<tr>
<th>Name</th>
<th>TubeType</th>
<th>Data</th>
<th>Modified</th>
<th>Status</th>
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<th>Combined</th>
<th>Extracted</th>
<th>History</th>
<th>Comment</th>
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<tr>
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<td>Combined 1/5 Octave</td>
<td>FFT</td>
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- **Extracted:** C
- **History:** Cal.17-6-09
- **Comment:** No comment.

---

Data and information exported to Excel
Step down the Task List to Export Results

Saves information in a propriety file that can be imported again later - *.fnc file

Transmission Loss

- Set up the tube system as shown below using the four microphones at once

Follow the instructions in the manual about placing the sample in the tube
Follow the software Task List in Pulse as before
From the Windows Task Bar select
Pulse/Applications/Acoustic Materials Testing in Tube/ Normal Incidence Transmission Loss

Follow task list steps as for Normal Incidence Absorption
The 7758 software offers two methods for normal incidence transmission loss testing in a tube, namely the one-load method and the two-load method. Brüel & Kjær strongly recommends use of the **two-load method**.

If you are considering using the one-load method please be aware that the termination of the tube needs to be truly anechoic. A non-anechoic termination will give rise to reflections which can cause significant errors in calculating transmission loss. These are avoided when the two-load method is used. Should you in any case choose to use the one-load method, you are advised to perform a "reality-check" by testing the same sample using both methods. Any deviation between the results from the one-load and two-load methods indicates that their termination of the tube used for the one-load method is insufficiently anechoic.

Note: If you change from large to small tube or vice versa, you must also change the frequency Span. We recommend that you also change the number of Lines for the FFT Analyzer in the measurement setup in order to maintain the same frequency resolution for example:

- Large tube: 1.6kHz, 400 lines (df = 4Hz)
- Small tube: 6.4kHz, 1600 lines (df = 4Hz)
Type 4002 Standing Wave Aparatus

Fig. 2.1. (Upper photo) The 4002 fitted with the short tube  
(Lower photo) The 4002 fitted with the long tube

Fig. 2.1 shows the 4002 assembled ready for use with both the short and the long tube. In the Microphone Carriage, which can run back and forth along the Graduated Track, is a small crystal microphone of adequate frequency range for the purposes of the standing wave tube method but which is not intended for other acoustic measurements. The microphone is mounted in elastic supports in the Microphone Carriage and is thus well insulated from external noise and vibration.

Fig. 1. Measuring arrangement for measuring the acoustic absorption coefficient

Laboratory Set up of Type 4002
THEORETICAL BASIS FOR MEASUREMENTS

Results obtained from the standing wave apparatus are applicable for sound incident normally to the surface of the sample and restrictions are placed on the use of the equipment to ensure that the theoretical conditions are closely approximate during the practical operation. The frequency range of the method is limited at the lower frequencies by the length of the measuring tube which must be at least 0.25 of the wavelength under consideration and at the higher frequencies by the diameter of the tube which theoretically should be less than 0.586 of the wavelength under consideration in order to exclude the possibility of transverse resonances with the tube.

ABSORPTION COEFFICIENT

Consider an acoustic plane wave incident normally on the sample in the standing wave tube. At a particular point, the sound pressure due to the incident wave at a particular instant of time is given by the equation:

\[ p_i = A \cos 2\pi ft \]  \hspace{1cm} (1)

and the sound pressure due to the reflected wave at the same point at the same instant of time disregarding the phase angle between the incident and the reflected wave is given by:

\[ p_r = B \cos 2\pi f \left( t - \frac{2y}{c} \right) \] \hspace{1cm} (2)

where

- \( p_i \) = sound pressure of the incident sound wave in Pa
- \( p_r \) = sound pressure of the reflected sound wave in Pa
- \( f \) = frequency of excitation in Hz
- \( y \) = distance of observed point from the surface of the sample in m
- \( c \) = velocity of sound within the tube in m.s\(^{-1}\)
- \( t \) = time in s

The total sound pressure at this point, \( p_y \), will therefore be:

\[ p_y = p_i + p_r = A \cos 2\pi ft + B \cos 2\pi f \left( t - \frac{2y}{c} \right) \] \hspace{1cm} (3)

By applying the Addition Theorem i.e.

\[ \cos (\theta - \phi) = \cos \theta \cdot \cos \phi + \sin \theta \cdot \sin \phi \] \hspace{1cm} (4)

to the ultimate term in Eqn.3, it can be seen that the sound pressure will have a maximum value of \((A + B)\cos 2\pi ft\) when \(y = \lambda/2\) and a minimum value of \((A - B)\cos 2\pi ft\) when \(y = \lambda/4\) where \(\lambda\) = wavelength = \(c/f\). A microphone situated at a distance \(\lambda/2\)
from the sample will therefore receive an alternating sound pressure of frequency $f$ and amplitude $(A + B)$.

The absorption coefficient of the sample is defined as the ratio between the energy absorbed by the sample to the total energy incident on the sample and as energy is proportional to the square of the sound pressure then

$$\alpha = 1 - \left( \frac{B}{A} \right)^2$$

(5)

This equation can be written

$$\alpha = 1 - r^2$$

(6)

where $r$ is the ratio between the reflected and the incident wave amplitudes i.e.

$$r = \frac{B}{A}$$

(7)

Using the standing wave apparatus, it is an easy matter to measure the ratio, $n$, of the maximum to minimum sound pressure in the tube that is the so called standing wave ratio:

$$n = \frac{P_{\text{max}}}{P_{\text{min}}}$$

(8)

$$\therefore n = \frac{A + B}{A - B}$$

(9)

An analogy can be drawn between this acoustic standing wave ratio and the standing wave ratio measured in electromagnetic wave guides.

Hence

$$\frac{B}{A} = \frac{n - 1}{n + 1}$$

(10)

Therefore the absorption coefficient can be expressed in terms of the standing wave ratio by substituting Eqn.10 in Eqn.5 yielding:
Fig. 3.2. The relationship between the absorption coefficient, $\alpha$, and the standing wave ratio, $n$

$$\alpha = 1 - \left(\frac{n - 1}{n + 1}\right)^2$$  \hspace{1cm} (11)

$$\therefore \quad \alpha = \frac{4n}{n^2 + 2n + 1}$$  \hspace{1cm} (12)

This relationship between the absorption coefficient and the standing wave ratio is expressed graphically in Fig. 3.2.

This measurement is made especially easy when a suitably calibrated scale is employed thus enabling the absorption coefficient to be read directly from the meter of the measuring amplifier. Such scales are available for all suitable B & K measuring amplifiers.

For Acoustic Impedance measurements see Type 4002 Manual in this folder.
PREPARATION AND POSITIONING OF SAMPLE

The 4002 possesses two tubes of different lengths and each tube is provided with three sample holders. The test material has to be carefully cut by employing a band saw, and the circular sample placed snugly into the sample holder. Porous material is cut so that it fits the internal diameter of the holder while absorption material with a hard covering plate, for example, acoustic tiling, is cut so that the hard plate fits the external diameter of the holder and the soft backing fits the internal diameter of the holder as seen in Fig. 4.1.

Fig. 4.1. Mounting of absorbive material in the tube
On the left: porous material
On the right: porous material faced with hard plate

By mounting the material in this manner, the front plate is held very firmly. The securing clamp, which braces the holder against the tube should be screwed on tightly in order to prevent vibrations occurring.

Hameg HM 8131 Function Generator into a Denon PMA 255UK Amplifier for Sine source

Measuring Amplifier Type 2610 for measuring
Received through a Type 1617 filter set

Input Section Gain 10dB steps
Output Section Gain 10dB steps
Input - Direct from microphone carriage

Filters
Ext- Off  Linear 2-200000Hz  A- Off
Detector
Normal  Normal  RMS
Using the Type 1617 Band Pass Filter Set

![Filter Set Image]

**Input Microphone**

<table>
<thead>
<tr>
<th>Selectivity</th>
<th>Range</th>
<th>Frequency</th>
<th>Averaging Control</th>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Sine 0.1secs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Filter Control Mode Manual</td>
</tr>
</tbody>
</table>

**MEASUREMENT OF SOUND ABSORPTION COEFFICIENT**

To measure the sound absorption coefficient one first completes the preparatory operations then:

1. Set the FREQUENCY DIAL of the Sine Generator so that the FREQUENCY DISPLAY indicates the frequency of interest. Turn up the OUTPUT VOLTAGE until the DISTORTION lamp lights then slightly reduce the OUTPUT VOLTAGE. A suitably high sound pressure level should then be present in the tube.

2. Move the microphone carriage up and down until a pressure maximum is detected within the tube i.e. the probe microphone is positioned at a pressure maximum.

3. Adjust the meter deflection on the 2606 by means of the INPUT SECTION ATTENUATOR and the DIRECT INPUT ‘sens.’ to 100% on the scale. N.B. At frequencies below 200Hz it may not be possible to find an isolated pressure maximum. In this case the pressure just in front of the sample should be used as a maximum.

4. Move the microphone carriage until the minimum nearest to the sample is indicated. The reason for measuring at this point is to minimise a possible error caused by sound attenuation along the tube. The absorption coefficient can then be read directly from the scale of the Measuring Amplifier. If the absorption be less than 70%, the gain on the amplifier can be increased by 10 dB and the absorption read from the 0 to 70% scale. If the absorption be less than 30% then the gain should be increased a further 10 dB and the absorption read from the 0 to 30 dB scale.

5. Repeat steps 1 to 4 for the other frequencies of interest and tabulate the results in tables as shown in Fig.4.4.

6. Remove the sample from the sample holder, reverse the sample holder and measure the absorption coefficient of the metal surface to determine the minimum measurable absorption coefficient.

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<th>125</th>
<th>160</th>
<th>200</th>
<th>250</th>
<th>315</th>
<th>400</th>
<th>500</th>
<th>630</th>
<th>800</th>
<th>1000</th>
<th>1250</th>
<th>1600</th>
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<td></td>
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<tr>
<td>Minimum measurable α</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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</table>

**Fig.4.4. Tabulation of absorption coefficient**
It is often useful to plot the absorption coefficient as a function of frequency. Fig. 4.5 shows the results obtained for a sample of fissured acoustic tile with a backing of mineral wool.

It should be remembered that the absorption coefficients as measured by the standing wave method are for normal incidence only which is why the measured coefficients are generally smaller than those determined by the reverberation room method and by employing Sabine’s formula. In the diffuse field of the reverberation room, sound is incident on the test sample from all angles. As of yet no reliable way has been devised for relating the results obtained from the two methods. (1979)

In 1961 however Bruel & Kjaer had this relationship in their Type 4002 Manual...
Using Ken’s Visual Basic program Normal - Random one can get an estimate of the Random Absorption Coefficient from the Normal Incident Octave Band point values extracted from the Impedance Tube measurements. This approach is only for materials that are porous absorbers and locally reacting.

Load up the text boxes with the Normal Incidence data and press the random button

ASTM C 384 - 03 offers a reference to a JASA paper by Albert London from 1950 that gives us a formula for this conversion.
To measure Absorption Coefficients in a tube other than at normal incidence would be useful. A Goniometer is a device that could do this if one had the room for it. Below is an Excel spreadsheet set up to measure Absorption Coefficients to obtain a NRC rating. Average between 250 Hz, 500 Hz, 1000 Hz and 2000 Hz values only.

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<th>C</th>
<th>D</th>
<th>E</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
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<td>Lmin (dB)</td>
<td>Lo (dB)</td>
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<td>22.8</td>
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<td>0.31</td>
<td>1&quot;</td>
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<td>53.0</td>
<td>10.1</td>
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<td>1&quot;</td>
<td>No air gap</td>
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<td>1&quot;</td>
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</table>

**Normal Incident Absorption Coefficient**

![Graph of Normal Incident Absorption Coefficient](image)

**Relation of Normal Incident Absorption Coefficient to Difference in Decibels Between Maximum and Minimum Sound Pressure Levels**

![Graph of Relation](image)
Comparison between 4002 and 4206 in 1/3 Octave band measurements

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<th>FREQ</th>
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<th>Lmin (dB)</th>
<th>Lo (dB)</th>
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<td>15.7</td>
<td>0.48</td>
<td>0.46</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Small Tube 4002 Standing Wave Apparatus</th>
<th>4206 Impedance Tube Measurement System</th>
</tr>
</thead>
<tbody>
<tr>
<td>FREQ</td>
<td>Lmax (dB)</td>
</tr>
<tr>
<td>800</td>
<td>102.2</td>
</tr>
<tr>
<td>1000</td>
<td>85.7</td>
</tr>
<tr>
<td>1250</td>
<td>90.7</td>
</tr>
<tr>
<td>1600</td>
<td>68.7</td>
</tr>
<tr>
<td>2000</td>
<td>70.9</td>
</tr>
<tr>
<td>2500</td>
<td>63.5</td>
</tr>
<tr>
<td>3150</td>
<td>56.5</td>
</tr>
<tr>
<td>4000</td>
<td>61.9</td>
</tr>
<tr>
<td>5000</td>
<td>67</td>
</tr>
<tr>
<td>6300</td>
<td>46.1</td>
</tr>
</tbody>
</table>

Red is Combined data from Calibration piece specifications
Brown data and graph is 4002 Measured data Large (Low f) tube
Purple data and graph is 4002 Measured data Small (High f) tube
Green data and graph is 4206 Measured data Large (Low f) tube
Light Blue data and graph is 4206 Measured data Small (High f) tube
Absorption Coefficient for Large Tube (Fig. 2)
Test condition: (Upper curve) Large tube setup with large calibration sample mounted.
(Lower curve) Sample removed. Piston in reference position.
Microphone positions: 2 and 3.
Frequency weighting: Linear

Absorption Coefficient for Small Tube (Fig. 3)
Test condition: (Upper curve) Small tube setup with large calibration sample mounted.
(Lower curve) Sample removed. Piston in reference position.
Microphone positions: 4 and 5.
Frequency weighting: High-pass

Environment
Ambient Pressure 1010.3 hPa
Relative Humidity 46 %
Temperature 25 °C

Date and Signature
7-Nov-2006 JI/45
Specifications 4002

**Specifications**

**Impedance/Transmission Loss Measurement Tubes**
Types 4206, 4206A, 4206T

**FREQUENCY RANGE**
- Large Tube: 50 Hz to 1,600 Hz
- Medium Tube: 100 Hz to 3,200 Hz
- Small Tube: 500 Hz to 6,400 Hz

**ZERO ABSORPTION**
(calculated in 1/3-octave bands)
- 50 Hz to 4 kHz: < 4%
- 5 kHz to 6.3 kHz: < 10%

**TUBE DIMENSIONS**

<table>
<thead>
<tr>
<th>Type</th>
<th>Inner Diameter [mm]</th>
<th>Max. Sample Length [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Meas. Tube</td>
<td>29 (1.1)</td>
<td>200 (7.9)</td>
</tr>
<tr>
<td>Medium Meas. Tube</td>
<td>63.5 (2.5)</td>
<td>200 (7.9)</td>
</tr>
<tr>
<td>Large Meas. Tube</td>
<td>100 (3.9)</td>
<td>440 (17.4)</td>
</tr>
<tr>
<td>Small Sample Holder</td>
<td>29 (1.1)</td>
<td>200 (7.9)</td>
</tr>
<tr>
<td>Medium Sample Holder</td>
<td>63.5 (2.5)</td>
<td>200 (7.9)</td>
</tr>
<tr>
<td>Large Sample Holder</td>
<td>100 (3.9)</td>
<td>200 (7.9)</td>
</tr>
<tr>
<td>Small Ext. Tubes</td>
<td>29 (1.1)</td>
<td>200 (7.9)</td>
</tr>
<tr>
<td>Large Ext. Tubes</td>
<td>100 (3.9)</td>
<td>200 (7.9)</td>
</tr>
<tr>
<td>Large TL Tube</td>
<td>100 (3.9)</td>
<td>260 (10.2)</td>
</tr>
<tr>
<td>Small TL Tube</td>
<td>29 (1.1)</td>
<td>200 (7.9)</td>
</tr>
<tr>
<td>Large TL Sample Holder</td>
<td>100 (3.9)</td>
<td>150 (5.9)</td>
</tr>
<tr>
<td>Small TL Sample Holder</td>
<td>29 (1.1)</td>
<td>65 (2.6)</td>
</tr>
</tbody>
</table>

**ASSEMBLED SETUP DIMENSIONS**
- Large Tube (length): 700 mm (27.7")
- Medium Tube (length): 910 mm (36")
- Small Tube (length): 850 mm (33.5")
- Large Tube (length): 1,170 mm (46.0")
- TL Large Tube (length): 1,080 mm (42.1")
- Total Width: 140 mm (5.5")
- Total Height: 240 mm (9.5")

**1/4" CONDENSER MICROPHONE CARTRIDGE**
TYPE 4187

To optimise the measurement accuracy of Type 4206, the microphones have a non-removable protection grid that forms an airtight front cavity. This gives a coupling between Type 4206 and the microphones that is well-defined with respect to phase.

**Open-circuit Sensitivity (250 Hz):**
- 4 mV/Pa (± 3 dB re 1 V/Pa)

**Capacitance (250 Hz):** 6.4 pF, typical

**Frequency Response Characteristic (Flush Mounted):** ± 1 dB; 1 Hz to 8 kHz

**Polarization Voltage:** 200 V

**LOUDSPEAKER**
- Max. Average Power: 10 W at 20°C (68°F)
- Max. Pulsed Power: 50 W for 2 s (limited by protection circuit)
- Impedance: 4 Ω
- Diameter: 80 mm (3.2")

**WEIGHT (WITH ACCESSORIES):**
- 12 kg (26.5 lb.)

*Add 200 mm for each extension tube used*

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**Specifications 4002**

**Frequency Range:**
- Large Tube: 90 Hz to 1,800 Hz
- Small Tube: 800 Hz to 6,800 Hz

**Dimensions of Measuring Tubes:**
- Large Tube:
  - Diameter: 99 mm (3.9")
  - Length: 1 m (39")
- Small Tube:
  - Diameter: 29 mm (1.14")
  - Length: 280 mm (11")

**Sample Holders:**
Each tube is provided with two sample holders with fixed depths of 25 mm (1") and 50 mm (2") and one sample holder with variable depth from 0 to 95 mm (3.75")

**Loudspeaker:**
- 7 in. 6 W, 4 Ω

**Microphone:**
(Crystal type)
- Sensitivity: 25 mV/Pa at 1,000 Hz (without probe)
- Capacitance: 2 nF
- Min. Load Impedance: 1 MΩ (≥ 3 dB at 90 Hz)

**Overall Dimensions:**
- Total length with large tube: 2.4 m (95")
- Total length with small tube: 1.66 m (65")
- Maximum width: 260 mm (10")
- Maximum height: 250 mm (10")

When dismantled the apparatus is compactly stored in the shipping container; the outer dimensions of which are:
- 1400 x 380 x 350 mm
- (55 x 15 x 14")

**Weight:**
- 48 kg (106 lb)