Acoustic laboratories ♯5
Measurement of sound absorption coefficients in the impedance tube

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Objectives: In this session, the students will measure the absorption coefficient of different kind of materials with the method of the impedance tube.

Material

- A B&K 4206 impedance tube with a calibration material sample.
- Different acoustic material samples to test.
- Two Larson-Davies 2520 1/4" condenser microphones and their preamplifier
- One B&K Type 2807-Two channels microphone power supply
- A B&K Pulse acquisition system that allows measuring complex frequency responses
- A Matlab license, or an acquisition software that allows a direct computation of absorption coefficient with transfer functions.
- You may want to access the ISO 10534-2 standard:
  - access the Sagaweb portal (http://sagaweb.afnor.org/en-US),
  - then click 'Access Saga Web', and click on 'I agree with the contract terms',
  - on the search page, write '10534-2' in the 'Search for' field, and select 'CI - ISO Collection' in the 'Collection' field, then click 'Search'
  - then you can download the french or english pdf document, or read it as html page.

1 Part 1: Theory

The reflection coefficient of a material is measured with an impedance tube. The sample to test is placed at one end of the tube, while the source is placed at the other end. Two microphones are placed on the surface of the tube, at a distance of respectively x_1 and x_2 of the sample (see Fig. 1).

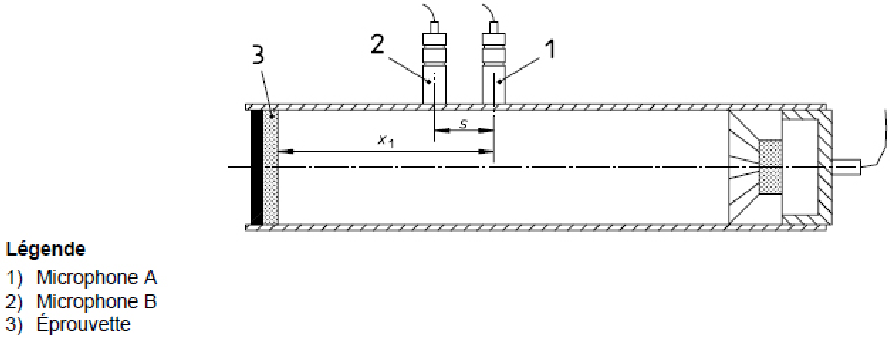


Figure 1: Dimensions and positions in the impedance tube

The ISO 10534 standard sets un upper and a lower frequency limit according to the tube dimensions. The upper frequency limit must satisfy the two following inequations:

$$f_u < 0.58\frac{c_0}{d}$$
$$f_u < 0.45\frac{c_0}{s}$$

where c_0 is the speed of sound in air, d is the diameter of the tube and s the distance between the two microphones. The first inequation guarantees the absence of transversal modes in the tube, and the second ensures a certain precision with a phase difference between the microphones of at least half a wavelength.
The lower frequency limit is given by the following inequation:

$$f_l = 0.05\frac{c_0}{s}$$

This condition ensures a significant amplitude difference between the two microphones.

Let's define the reflection coefficient R, as the ratio between the sound pressure reflected at the end of the tube (retrograde wave) over the incident pressure (progressive wave):

$$R = \frac{p_r}{p_i}$$

If we express the total sound pressures at positions x_m $(m = 1, 2)$ as:

$$p_t(x_m) = p_i(x_m) + p_r(x_m) = p_i(0).(e^{jkx_m} + Re^{-jkx_m}),$$

we can define $H_{12} = \dfrac{p_t(x_2)}{p_t(x_1)}$ the transfer function between sound pressures at microphones 1 and 2. We can also express similar transfer functions for the only incident and reflected sound pressures respectively: $H_I = \dfrac{p_i(x_2)}{p_i(x_1)} = e^{-jk(x_1-x_2)}$ and $H_R = \dfrac{p_r(x_2)}{p_r(x_1)} = e^{+jk(x_1-x_2)}$.

Question:

1. Give the frequency limitations of the two tubes diameters (Note: large tube $d_l = 10$ cm, and small tube $d_s = 5$ cm).

2. Show that:

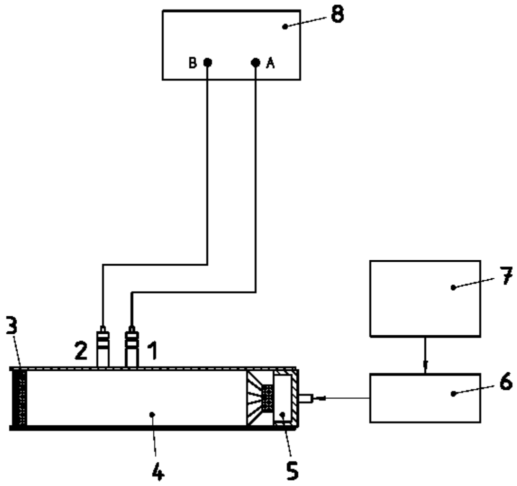
$$R = \frac{H_{12} - H_I}{H_R - H_{12}}e^{2jkx_1}$$

2 Part 2: Measurements setup

2.1 Setting the instrumentation

The measurement setup procedures is the following:

- Prepare the measurement setup as described in Figure 2. The microphones will be connected to input 1 and 2 of the Pulse Hardware, and the amplifier is connected to output 1 (connector # 5 of the Pulse Hardware).
- Click on the Windows Start Menu and click on the 'Pulse Labshop' icon. Click a 'Create a Blank Project' in the 'New Project' tab (don't select 'Create New Project').
- Wait for the software initialization: the connection to the Hardware may take about 30 seconds, and it is ready when the Front-end icon on the bottom right part of the window is visible ().



Légende
1 Microphone A
2 Microphone B
3 Éprouvette
4 Tube d'impédance
5 Source sonore
6 Amplificateur
7 Générateur de signal
8 Système d'analyse de fréquece

Figure 2: Meaurement setup

2.1.1 Configuration Organiser:

When initialization is over, press 'Ctrl+1' and define the Hardware input:

- Right-click on Input 1/2, click on 'Select Transducer'. In the 'Database Administrator', select 'Microphone' family, and chose Type '130D20' for both channels
- Rename the input as 'mic1' and 'mic2'

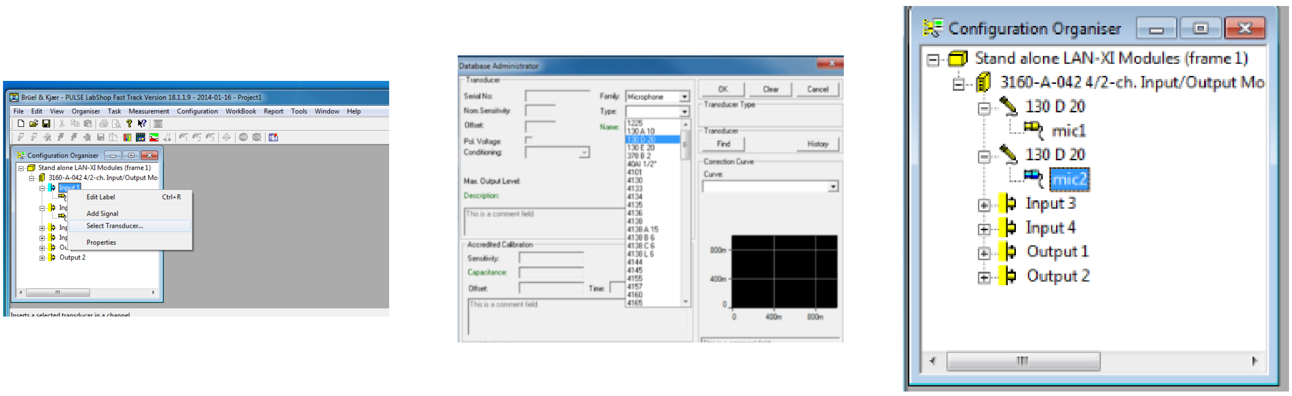


Figure 3: Hardware configuration: left: channel selection; center: transducer selection; right: channel renaming

2.1.2 Measurement Organiser:

Press 'Ctrl+2' and define the analysis framework:

- In the 'Measurement Organiser' tab, right-click on 'Setup' and chose 'Insert → FFT Analyzer'. Repeat the operation and chose 'Insert → Generator'.
  When you create the 'FFT Analyzer' object, the 'Frontend' branch gets populated with 'Signals' and 'Groups'. Check that 'mic1' and 'mic2' are actually visible in the 'Signals' branch. then right-click on the 'Groups' branch and select 'New Group'. Right-click on the 'Signal Group 1'

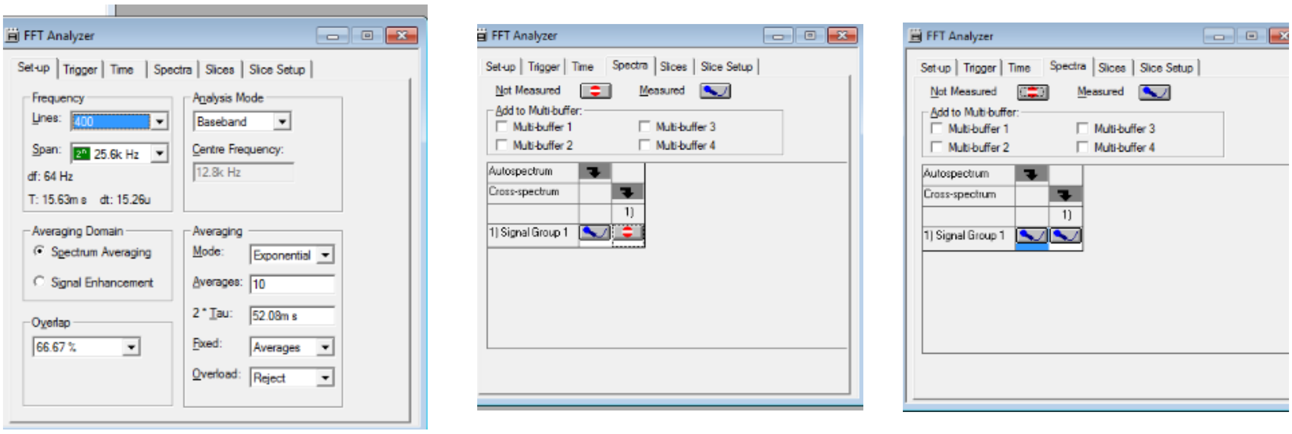
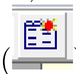


Figure 4: FFT analyser configuration: left: general FFT properties; center: cross-spectrum deactivated; right: cross-sepctrum activated

branch and select 'Insert Signal → mic1'. Repeat the operation and insert also 'mic2'.

FFT Analyzer configuration

Once Signal Group 1 is created and assigned the signals 'mic1' and 'mic2', you can configure signal processing on the selected group.

- Right-click on 'FFT Analyzer' and select 'Insert Group → Signal Group 1'.
  Once the signal group 1 is selected, click the 'F2' button, or go to 'Measurement → Activate Template', or click the top-right button in the task bar ().
- Right-click on 'FFT Analyzer' and select 'Properties'. It opens the 'FFT analyzer' setting panel
- In the 'Set-up' tab, chose the frequency resolution that you want to apply.
  Question:
  1. In the 'Frequency' panel, what Frequency Span would you chose, according to the frequency limitation f_l and f_u defined for the (large) impedance tube?
  2. What should be the 'Lines' number to get a frequency resolution of 1 Hz ?
  3. In the 'Analysis Mode' panel, you can select 'Baseband' (analysing from 0 Hz to f_u) or 'Zoom' (analyzing from f_l to f_u). Select 'Zoom' and enter the correct Centre Frequency to analyze from f_l up to f_u.
  4. In the 'Averaging' panel, select 'Linear' Mode, and set the number of averages to set the measurement time to 20 s (keeping an 'Overlap' of 66.67%)
- Go to the 'Spectra' tab, and check the box 'Cross-spectrum' in the 'Signal Group 1' raw. It should show an 'Forbidden' symbol. Click on it to change it into a 'Microphone' symbol.
- Activate Template (F2).

Generator

You can now right-click on the 'Generator1' branch, and select 'Properties'. Then you can set the generator parameters for the measurement (see Fig. 5).

Question:

5. We want to excite the impedance tube with a stationnary broadband noise, of bandwidth containing $[f_l f_l]$. Modify the fields 'Spectral properties' to that end.

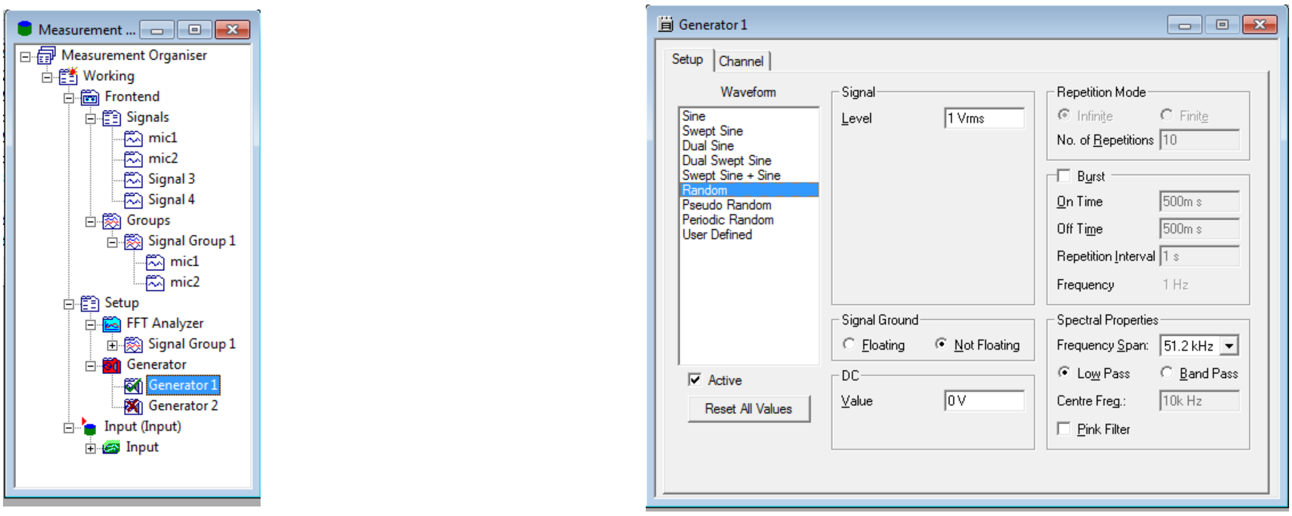
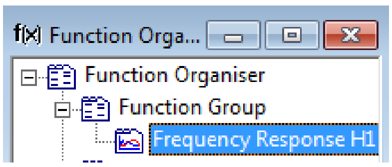


Figure 5: Generator configuration

2.1.3 Function Organizer

Now you will define the functions you want to process. We will first process the transfer function H_{12}.

- Press Ctrl+3. right-click on 'Function Group' and select 'Insert'. It creates a new function (by default it is 'Autospectrum(mic1)').
- Right-click on 'Autospectrum(mic1)' and select properties.



Question:

6. Select the Frequency function 'H1'. What are the signals to select in 'Signal' and 'Reference signal' to process H_{12}?

- After having organized your measurement session, place a calibration sample in the tube.

2.2 Calibration

In the proposed measurement setup, the microphones do not need to be calibrated (ie. we don't need to know their sensitivity in mV/Pa). Instead, we will use a known absorbing sample (here a disk of glass wool), and do a 2-step calibration procedure, as explained in the ISO 10534-2 standard. First, create a folder on the computer to save all measurements.

- Measure the transfer function between the microphones and save the result as "H12.txt" (you can directly right-click on the curve and select 'Save as').
- Then switch the 2 microphone positions and do the same measurements, and save the result as "H21.txt".

Question:

7. Draw the transfer functions H_{12} and H_{21} on Matlab. Comment the result.
   For importing measurement data in Matlab, you can use import data tool, then select the file you want to download (H12.txt or H21.txt), and define the range (raw numbers, columns numvers) corresponding to the measurement data, after the header. You should have 4 columns:
   - the frequency bin (ie. the index of each measurement frequency, from 1 to the size of the frequency vector defined at the beginning),
   - the frequency in Hz,
   - the real part of H_{12},
   - the imaginary part of H_{12},

You may disregard the 1^{st} column. The import data tool creates 'cells', which are not numeric format. To process the data, you may use the function 'cell2mat'.

Once the calibration transfer functions H_{12} and H_{21} are saved on the computer, the calibration factor can be expressed as $H_c = \sqrt{H_{12}H_{21}}$ which allows correcting some phase differences between the microphones. From now on, each transfer function H_{12} you will measure need to be corrected by the calibration factor as:

$$H_{12c} = \frac{H_{12}}{H_c}$$

Question:

8. In Matlab, create a code allowing you processing the reflection coefficient R and the absorption coefficient α of the material sample, according to the method of ISO 10534-2 standard. Compare the measured sound absorption coefficient with Figure 6.

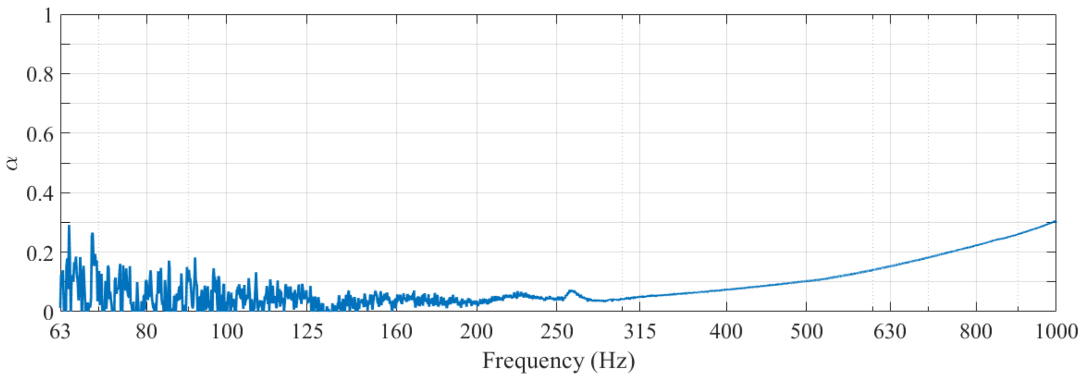


Figure 6: Absorption coefficient measured with the calibration sample

3 Absorption coefficient measurements

Question

9. Measure the absorption coefficient of the plaster and wood samples. Draw their absorption curve for the frequency bandwidth corresponding to the tube dimensions. Present the whole results on a single graph.

10. Measure the absorption coefficient with the glass wool sample and different thickness of plenum at the back (select a 5 cm step, from the smallest plenum size up to the maximal value). Draw the different curves on the same chart, and comment the results.