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Acoustics for the 21st Century…

Characterization of Mufflers

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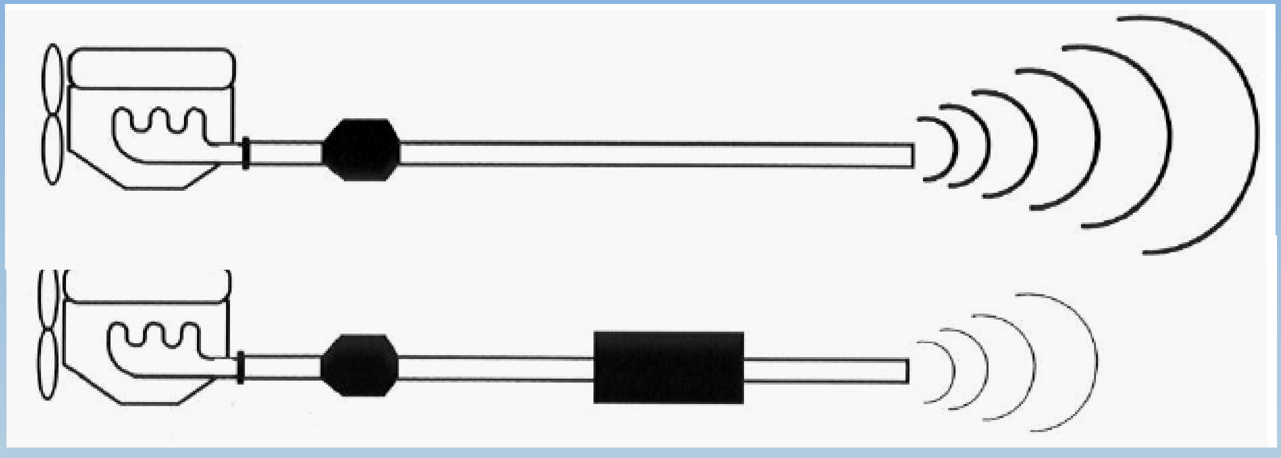
Motivation

- Mufflers are devices used to reduce noise emitted from different fluid machines
- They have to be tailored to each machine
- Tailoring means that we need simulation tools and measurement techniques to validate the models.



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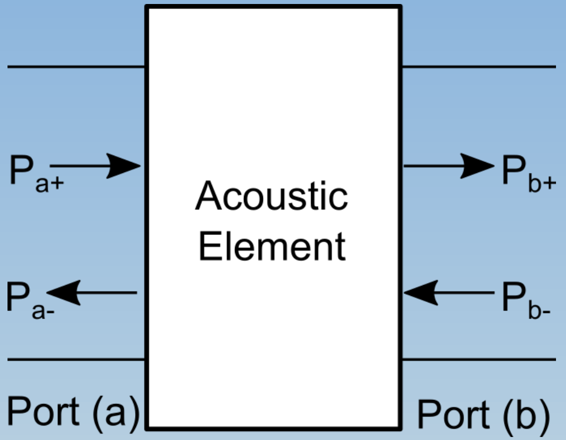
Motivation

- Measurements are done in universities, Research Institutes and Companies
- They are repeated regularly
- Requirements:
  - Standardize the procedure
  - Minimize the time to conduct one measurement
  - Make it easy for everyone to do the test

The acoustic two port theory

- The wave propagation inside an acoustic element (muffler) can be described by the scattering matrix formulation:

$$\begin{bmatrix} p_{a+} \\ p_{b+} \end{bmatrix} = \begin{bmatrix} R_{11} & T_{12} \\ T_{21} & R_{22} \end{bmatrix} \begin{bmatrix} p_{a-} \\ p_{b-} \end{bmatrix} + \begin{bmatrix} p_{a+}^{s} \\ p_{b+}^{s} \end{bmatrix}$$



Two source technique

- It is a technique which is widely used to characterize mufflers using stepped sine excitations especially in the presence of flow

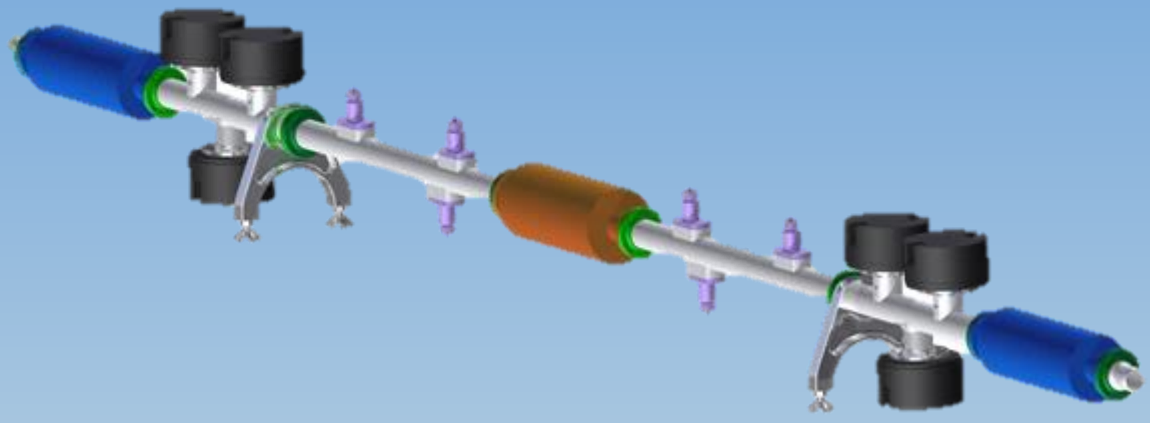


Fig. 1: Typical two source setup

The two source technique

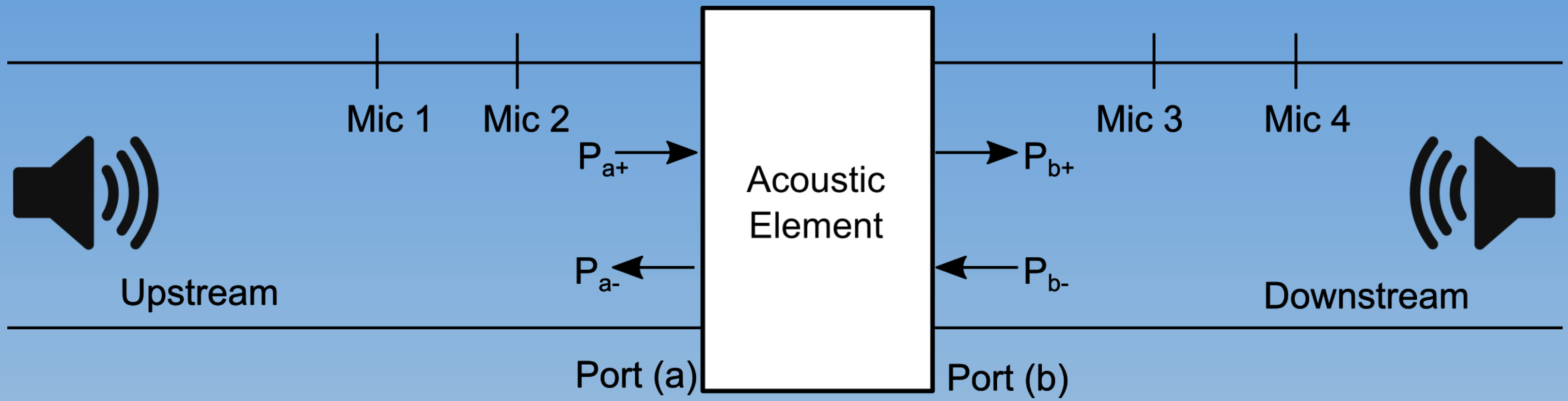
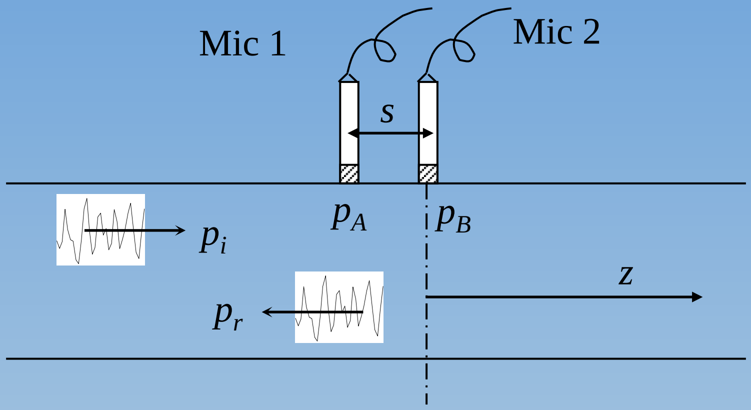


Fig. 2: Two-source setup schematic

$$\begin{bmatrix} p_{a+} \\ p_{b+} \end{bmatrix} = \begin{bmatrix} R_{11} & T_{12} \\ T_{21} & R_{22} \end{bmatrix} \begin{bmatrix} p_{a-} \\ p_{b-} \end{bmatrix} + \begin{bmatrix} p_{a+}^{s} \\ p_{b+}^{s} \end{bmatrix}$$

Wave Decomposition
Two-microphone Technique

- Two-microphone wave decomposition techniques used to determine downstream and upstream propagating waves.



- Frequency Range?
  - Limitation 1: Plane waves inside the pipe → $f_u < 0.58\ c_0/d$
  - Limitation 2: Microphone spacing → $0.1\pi(1-M^2) < ks < 0.8\pi(1-M^2)$

The two source technique

It can be used to estimate the acoustic performance of a muffler by measuring the:

- Elements of the scattering matrix
- Transmission loss

$$TL = 10\log_{10}\left[\frac{(1+M_k)^2 Z_l}{(1+M_l)^2 4Z_k}\left|T_{red,11} + \frac{T_{red,12}}{Z_l} + Z_k T_{red,21} + \frac{T_{red,22} Z_k}{Z_l}\right|^2\right]$$

- Insertion loss

$$IL = 10\log_{10}\left[\left|\frac{T_{red,11}Z^{ls} + T_{red,12} + Z^{ks}\left(T_{red,21}Z^{ls} + T_{red,22}\right)}{T^{ref}_{red,11}Z^{ls} + T^{ref}_{red,12} + Z^{ks}\left(T^{ref}_{red,21}Z^{ls} + T^{ref}_{red,22}\right)}\right|^2\right]$$

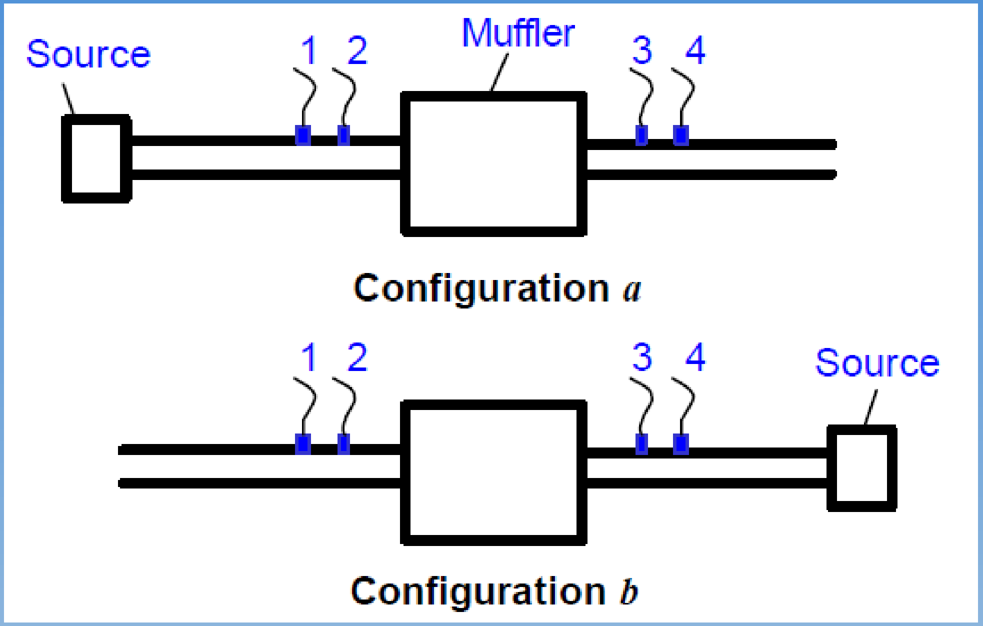
- Noise reduction

$$NR = 20\log_{10}\left[\left|T_{red,11} + \frac{T_{red,12}}{Z^{ls}}\right|\right]$$

Problem statement

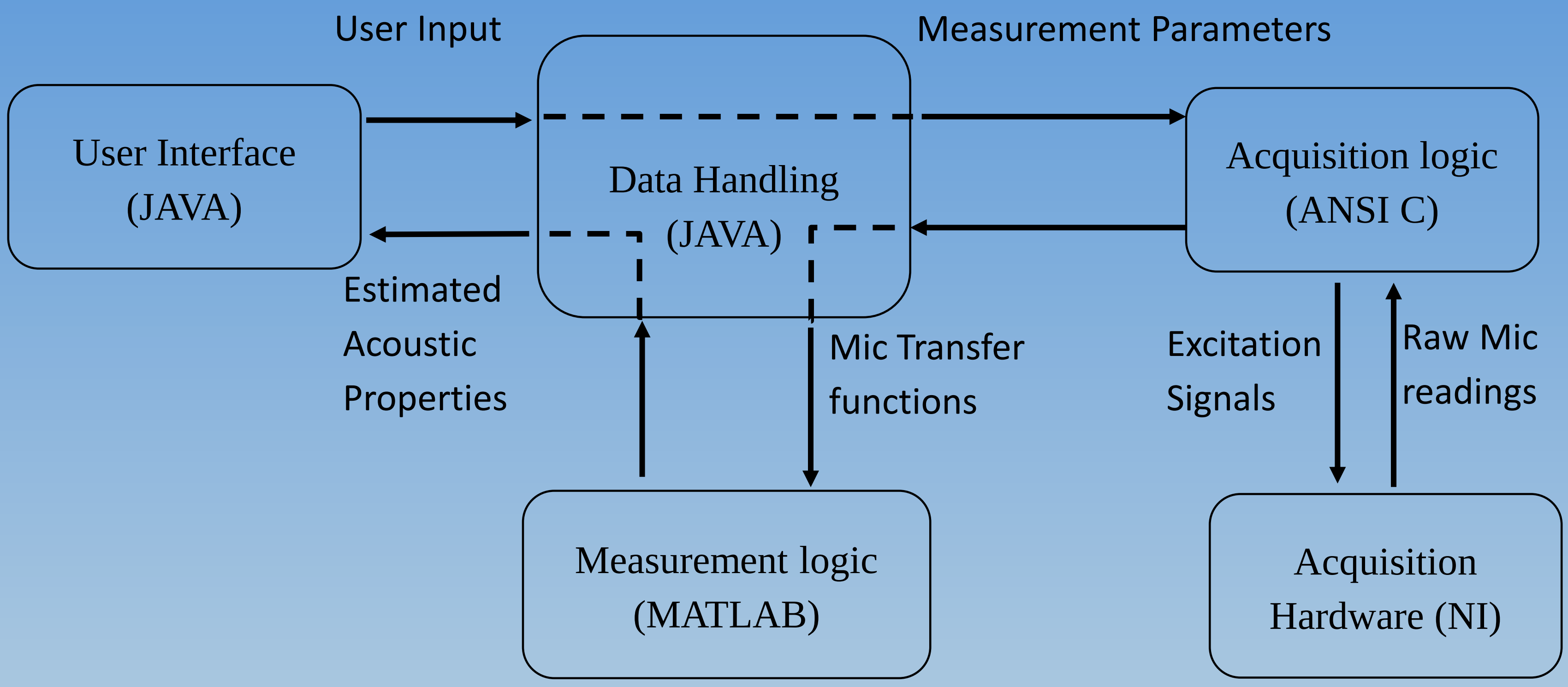
- The evaluation of the acoustic performance of a muffler using stepped sine measurements takes a considerable amount of time
- We introduce a new platform to automate the two-source technique which:
  - Reduces the time required to perform stepped sine measurements
  - Maintain the accuracy provided by traditional platforms

Solution approach



- The measurement time is reduced by developing a new platform which:
  - Introduces a new acquisition algorithm to optimize the measurement time
  - Implements simultaneous upstream and downstream stepped sine excitation

Construction of the new platform



Optimized acquisition algorithm

Reference algorithm:

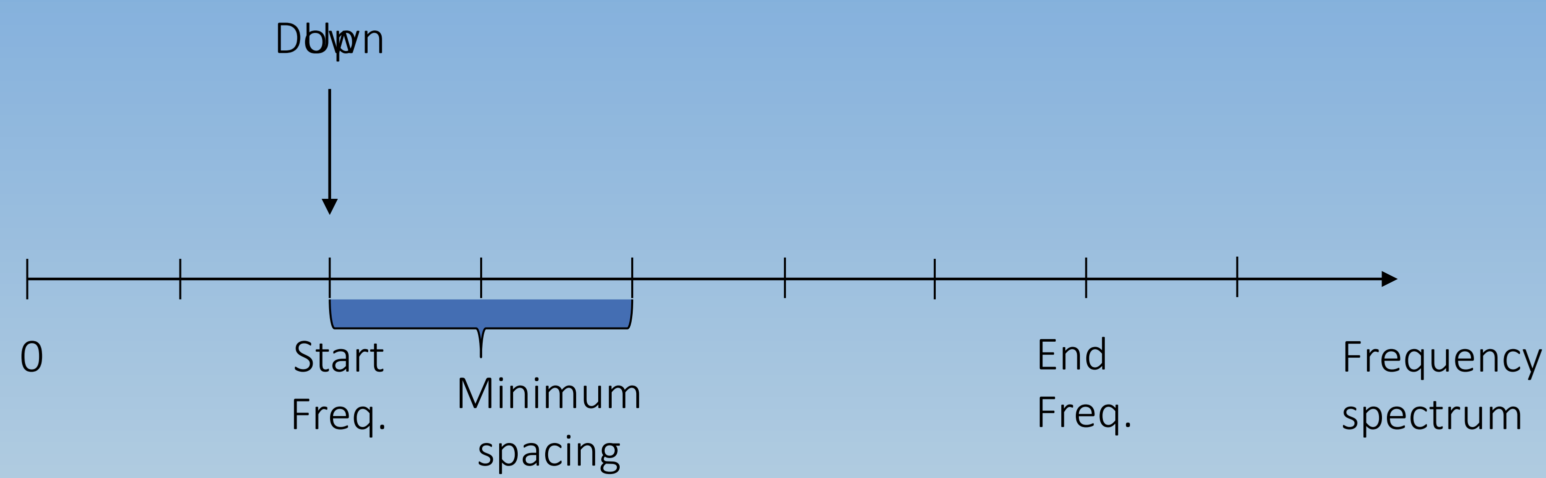
- The sampling rate is fixed and depends on the maximum frequency to be excited
- The data window size is determined by the desired frequency step size
- The excitation is stopped between each two frequency steps

Optimized algorithm:

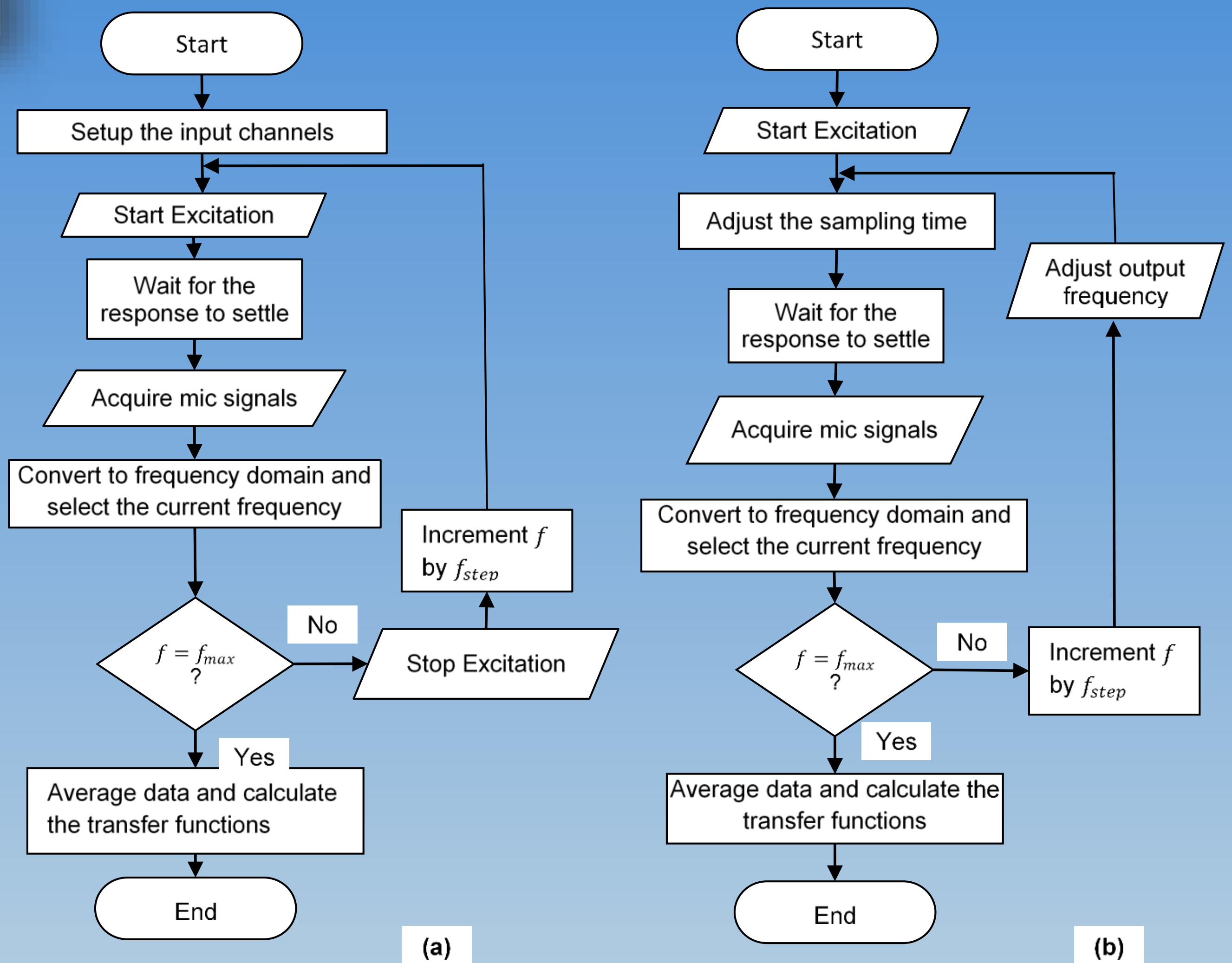
- The sampling rate depends on the frequency being excited
- The data window size is fixed
- The excitation is kept between each two frequency steps, only the frequency is changed

Simultaneous excitation

- Traditionally only one speaker (upstream or downstream) is excited at a time
- Simultaneous excitation involves exciting both upstream and downstream speakers at the same time but at different frequencies:



Conventional vs. Optimized Acquisition



Algorithm validation

The results obtained by the following methods were compared:

- The new platform with:
  - Optimized acquisition algorithm
  - Optimized algorithm and simultaneous excitation
- SIDLAB commercial software
- Analytic simulations using the acoustic two port theory

Validation setup

Test Cases:

- Straight pipe ($\mathrm{L}=1\ m,\ \ D=50\ mm$)
- Dissipative muffler ($\mathrm{L}=0.5\mathrm{m},\ \ \mathrm{D\_i}=50\ \mathrm{mm},\ \ \mathrm{D\_o}=99\ mm$, 20% porosity)

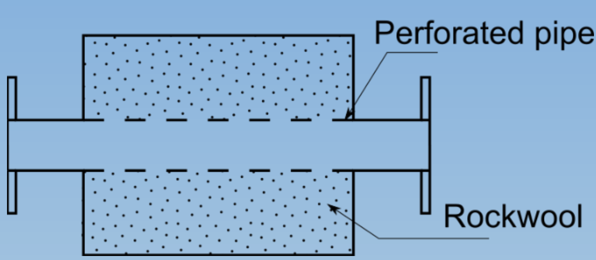


Fig. 3: Schematic for the dissipative muffler

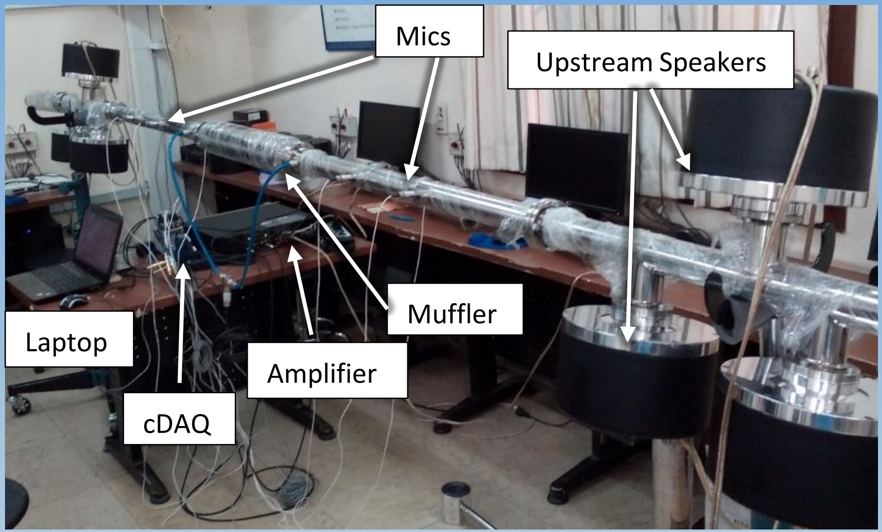
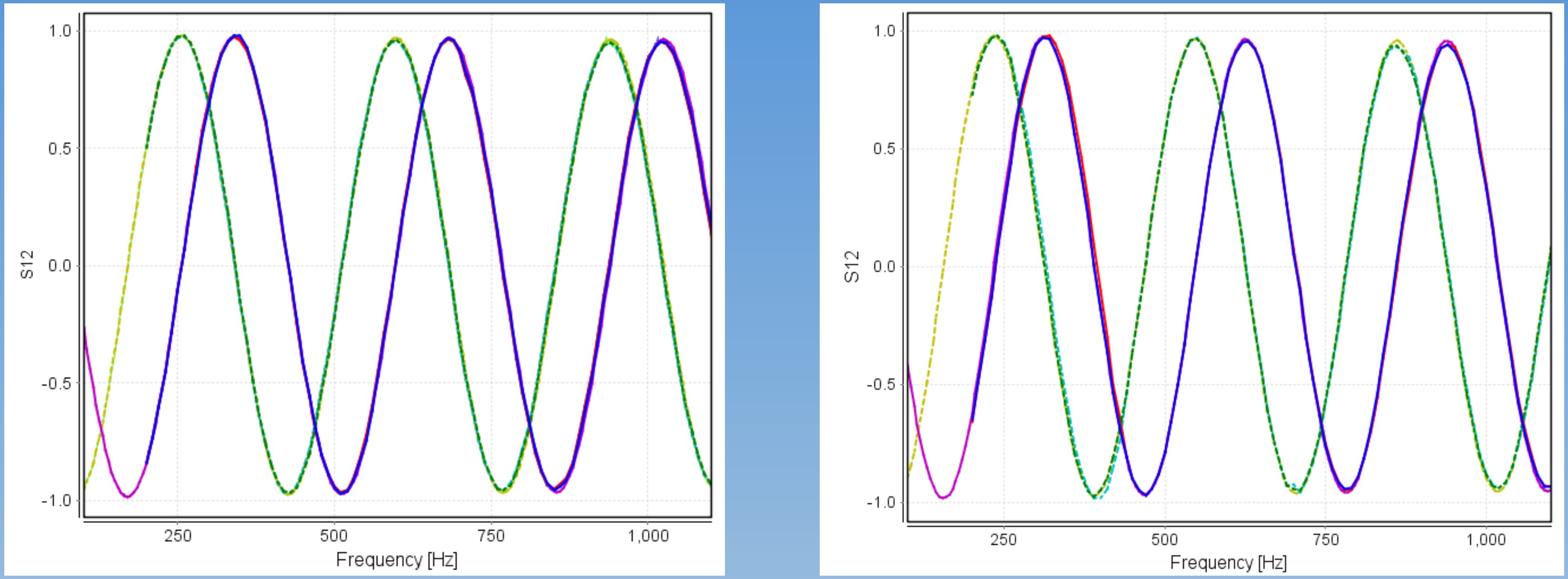


Fig. 4: The used test setup for validation

Straight pipe results

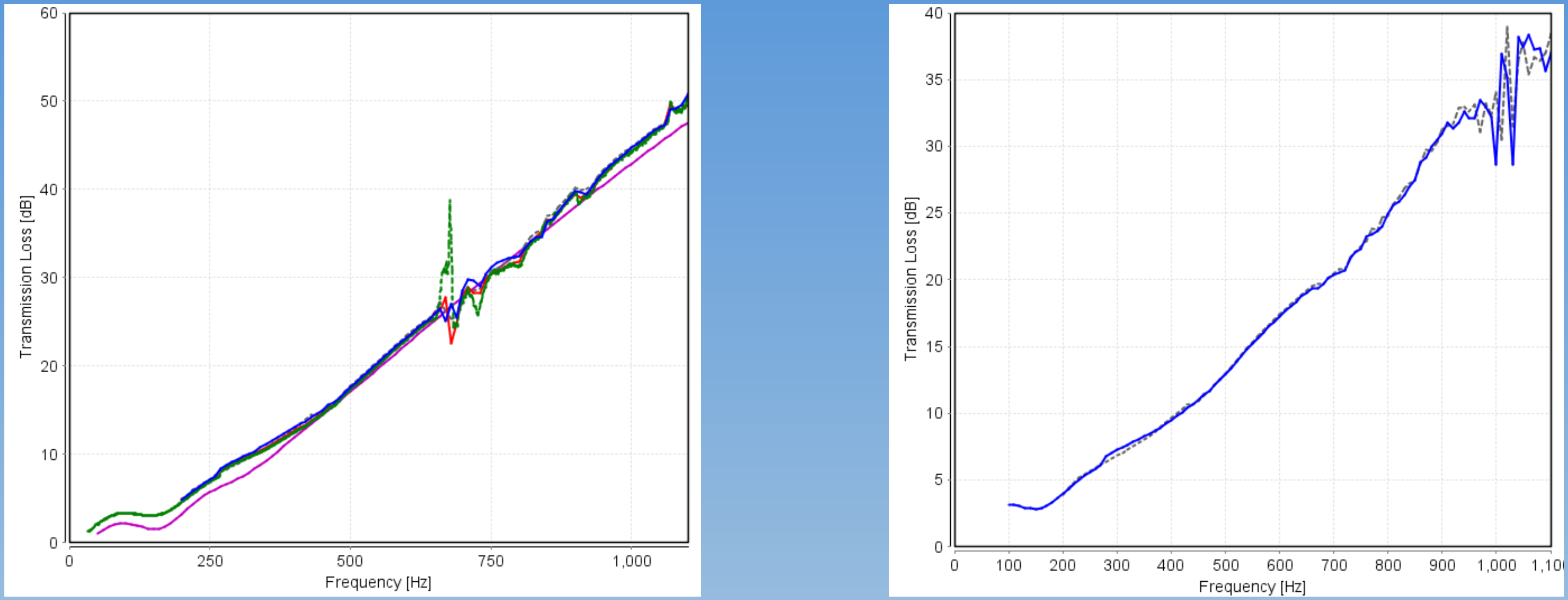


(a) Without flow

(b) With flow (M=0.1)

Fig. 5: Real and imaginary components of S_{12} estimated using simultaneous stepped sine (Real part and Imaginary part), white noise (Re and Im), optimized single-sided stepped sine (Re and Im), conventional stepped sine excitations (Re and Im) and analytically (Re and Im)

Dissipative muffler results



(a) Without flow

(b) With flow (M=0.1)

Fig. 6: TL of the dissipative muffler estimated using simultaneous stepped sine, white noise, optimized single-sided stepped sine, conventional stepped sine excitations and analytically

Time improvements

The total acquisition time (t_a) taken by the different acquisition algorithms within a frequency range between 200 and 1100 Hz, a step of 10Hz and 100 averages was measured to be:

Acquisition algorithm	t_a (min)	Speed Gain
Conventional	32.0	-
Optimized	9.1	3.5
Optimized with simultaneous excitation	6.0	5.3

Summary

- A new platform for the automation of two source acoustic measurements is introduced and validated
- The new platform minimizes the time needed to perform the measurements without affecting their quality
- The new platform can be as much as 5 times faster than reference implementations