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Validation of Micro-Perforated Panels Models

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Outline

❖ Models for the Micro-perforated Panel

- Maa Model
- Modified Maa Model
- FEM Model (based on rigid porous frame)

❖ Advance for Impedance Tube

- Four Microphone Impedance Tube Measurement
- Error Analysis & Calibration Procedure

❖ Results & Conclusion

❖ Future Work

- Modified FEM Model
- Elastic Porous Frame

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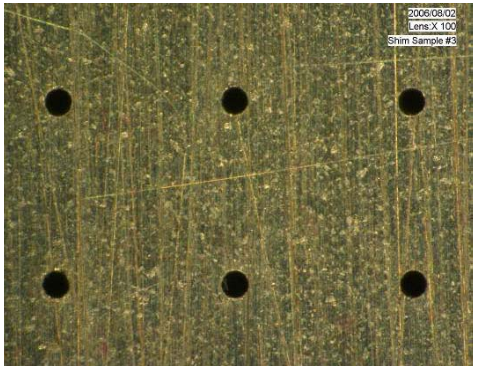
Introduction to the MPP & Maa Model

☺*Environmentally friendly*
☺*Good low frequency performance*
☺*Affordable in the recent!*



Classical Maa Model (1998)

☹*No Flexural Motion*
☹*No hole interaction*
☹*Resistive Underestimation*

Classical MPP Models:
- Maa Model (1975, 1987, 1998)
- Allard's Modal Approach
- Beranek/Ingard Model
- ……

MPP Models Validation:
- Analytical~Maa Model (1987)
- Numerical~Finite Element Method
- Experimental~Four Microphone Impedance Tube

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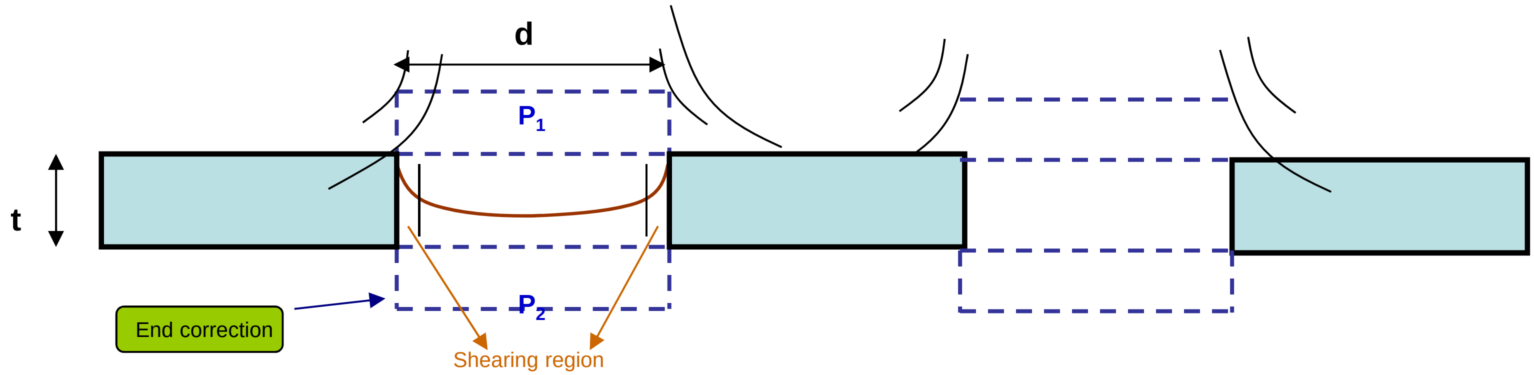
Modified Maa Models



MPP Impedance

$$z = \frac{Z_1}{\phi \rho_0 c} = r + j\omega m$$

- Z_1: specific acoustic impedance
- ϕ: porosity
- *r* : resistance
- *m*: effective mass per unit area
- *x*: perforation constant

Modified 1987 Version

$$r = \frac{32\eta}{\phi \rho c}\frac{t}{d^2}\left(\sqrt{1+\frac{x^2}{32}} + \beta\alpha\sqrt{\frac{2xd}{8t}}\right)$$

$$m = \frac{t}{\phi c}\left(1 + \frac{1}{\sqrt{9+\frac{x^2}{2}}} + 0.85\alpha\frac{d}{t}\right)$$

Contribution from hole | End corrections

Based on Ingard's semi-empiristic formula for perforated panels

$\alpha = 1 - 3\sigma$ ***Account for the hole interaction***

$\beta = 1.5$ ***Introduce constant parameter to modify the resistive end correction***

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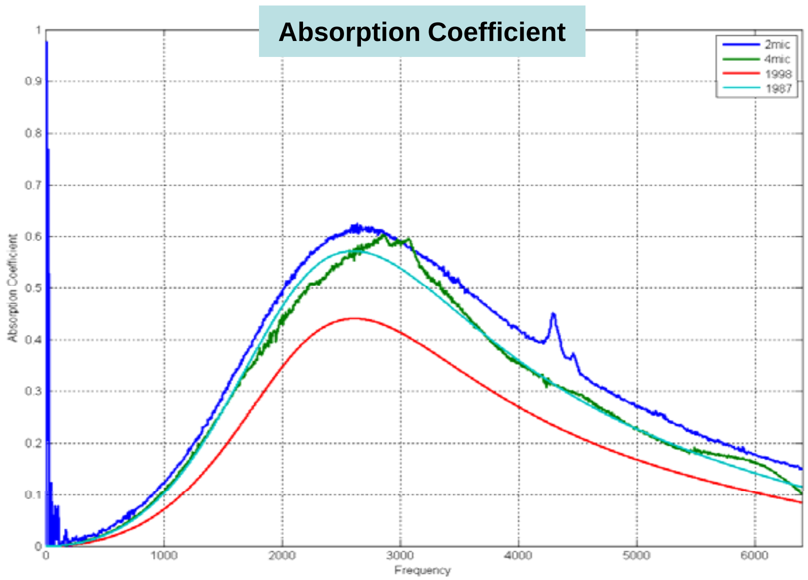
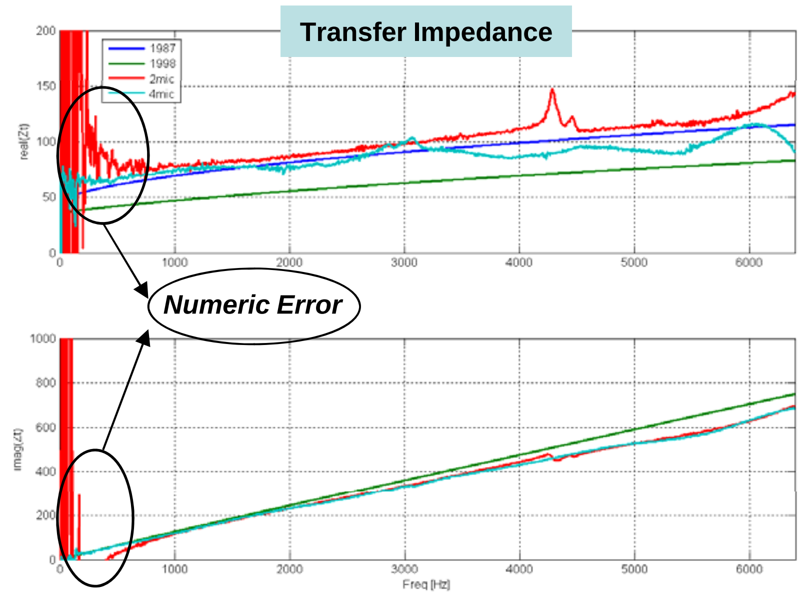
Absorption Coefficient & Transfer Impedance





$$\alpha_n = \frac{4r}{(1+r)^2 + \left(\omega m - \cot\left(\frac{\omega L}{c}\right)\right)^2}$$

2-Microphone & 4-Microphone

- Resistive part determines absorption peak location
- Reactive part determines absorption peaks height

- A straightforward way to investigate the material impedance
- Avoid the numeric error

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Finite Element Model

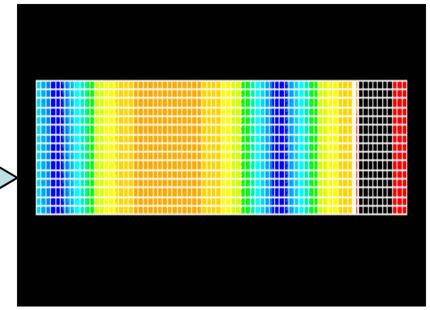
MPP

Johnson-Allard Model

Equivalent Tortuosity

Rigid Porous Material

Software Simulation



Finite Element Model

ϕ: porosity
σ: flow resistivity
Λ: viscous char length
Λ': thermal char length
α_∞: equivalent tortuosity

Parameters Required

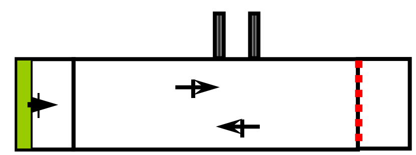
$$\Lambda = \Lambda' = \frac{d}{2}$$

$$\sigma = \frac{32\,\eta}{\phi d^2}$$

$$\alpha_\infty = 1 + \frac{2\varepsilon_e}{t}$$

$$\varepsilon_e = 0.48\sqrt{\pi r^2}\,(1 - 1.14\sqrt{\phi})$$

All the existing models can be obtained from an equivalent fluid model by selecting the appropriate parameters



Impedance Tube

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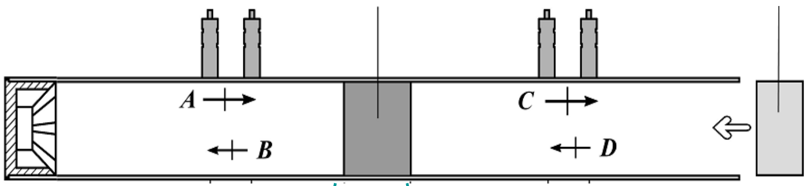
Recent Development for the Impedance Tube

- Standard Two Microphone Impedance Tube Measurement { ISO 10534-2, ASTM E 1050
- Four Microphone Impedance Tube Measurement

better suited for extraction of material properties { complex wave number, complex characteristic impedance



$$P|_{x=0} = (A+B)$$
$$V|_{x=0} = (A-B)/\rho_0 c$$

$$P|_{x=d} = (Ce^{-jkd} + De^{jkd})$$
$$V|_{x=d} = (Ce^{-jkd} - De^{jkd})/\rho_0 c$$

$$\begin{bmatrix} P \\ V \end{bmatrix}_{x=0} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} P \\ V \end{bmatrix}_{x=d}$$

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} = \begin{bmatrix} \cos k_p d & j\rho_p c_p \sin k_p d \\ j \sin k_p d / \rho_p c_p & \cos k_p d \end{bmatrix}$$

Transfer Impedance

$$Z_t = P_0/V_0 - P_d/V_d$$

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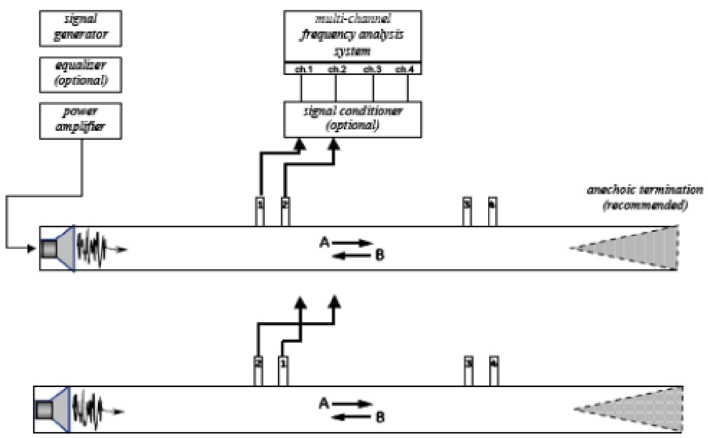
Non-Switching Approach

Error Sources

- Microphone Mismatch
- Bias Error
- Tube Attenuation



Single microphone moves to location 1,2,3,4

- For low transmission loss materials, phase mismatch is major concern
- Non-Switching approach can avoid phase mismatch phenomenon
- Accuracy depends on the stationary of electronic systems and FFT average

Corrected factor

$$H^{c}_{21} = (H^{I} \cdot H^{II})^{1/2}$$

Corrected transfer function

$$\widetilde{H}_{21} = H_{21} / H^{c}_{21}$$

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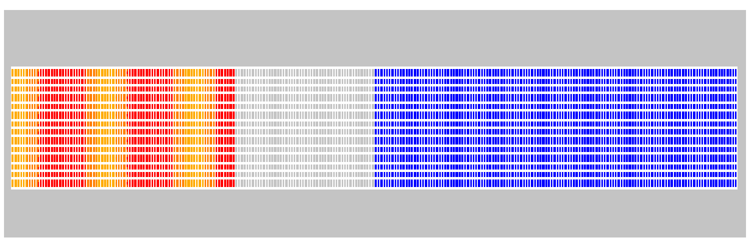
Experiment Setup

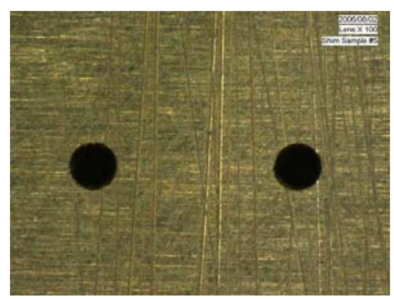
Hardware: B&K Type 4206
(2.9cm diameter)

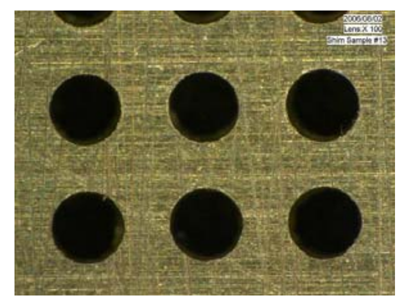
Software: COMET/ACOUSTICS-SAFE



Tested Material: Brass Sample

Sample Number	Diameter d [mm]	Hole Depth t [mm]	Porosity φ[%]
1	0.2032	0.8128	3
2	0.4064	0.8128	8
3	0.6096	0.8128	9
4	0.4064	1.2192	12
5	0.6096	1.2192	18
6	0.6096	0.8128	27





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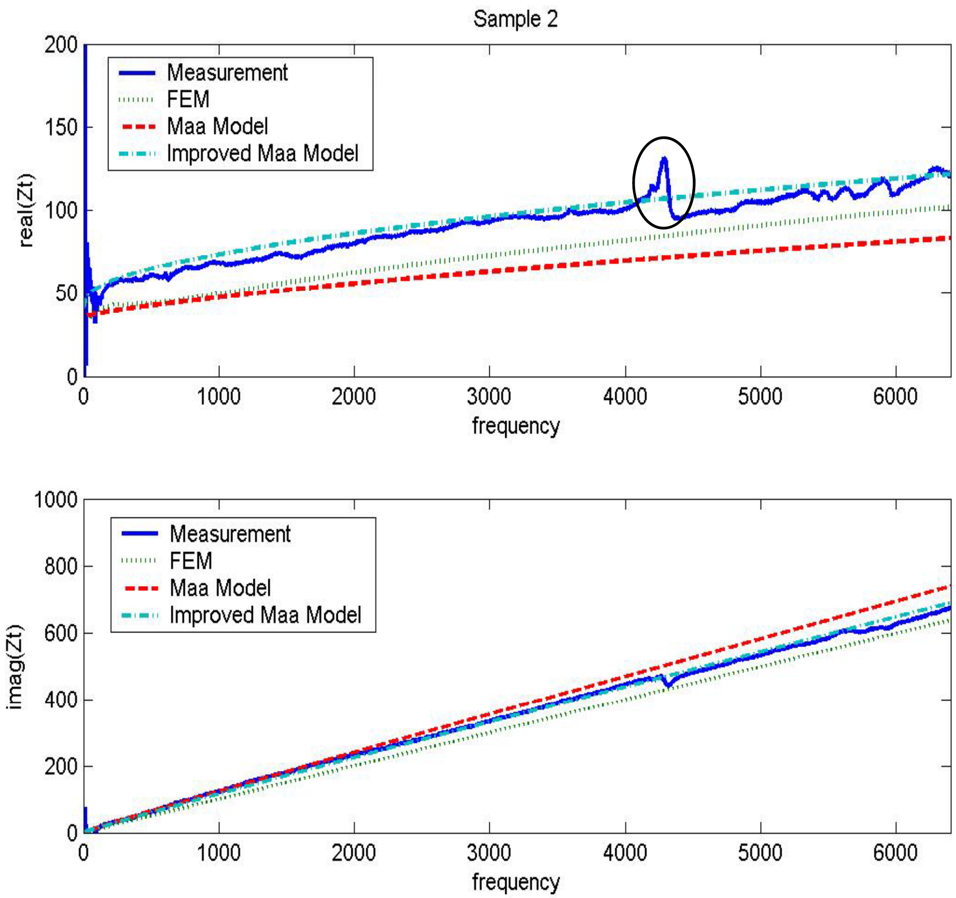
Results-Low Perforation Rate



- ❖ Maa Model underestimate resistive part of the impedance in low perforation rate case
- ❖ FEM model is acceptable
- ❖ The highlighted peak comes from the flexural panel vibration

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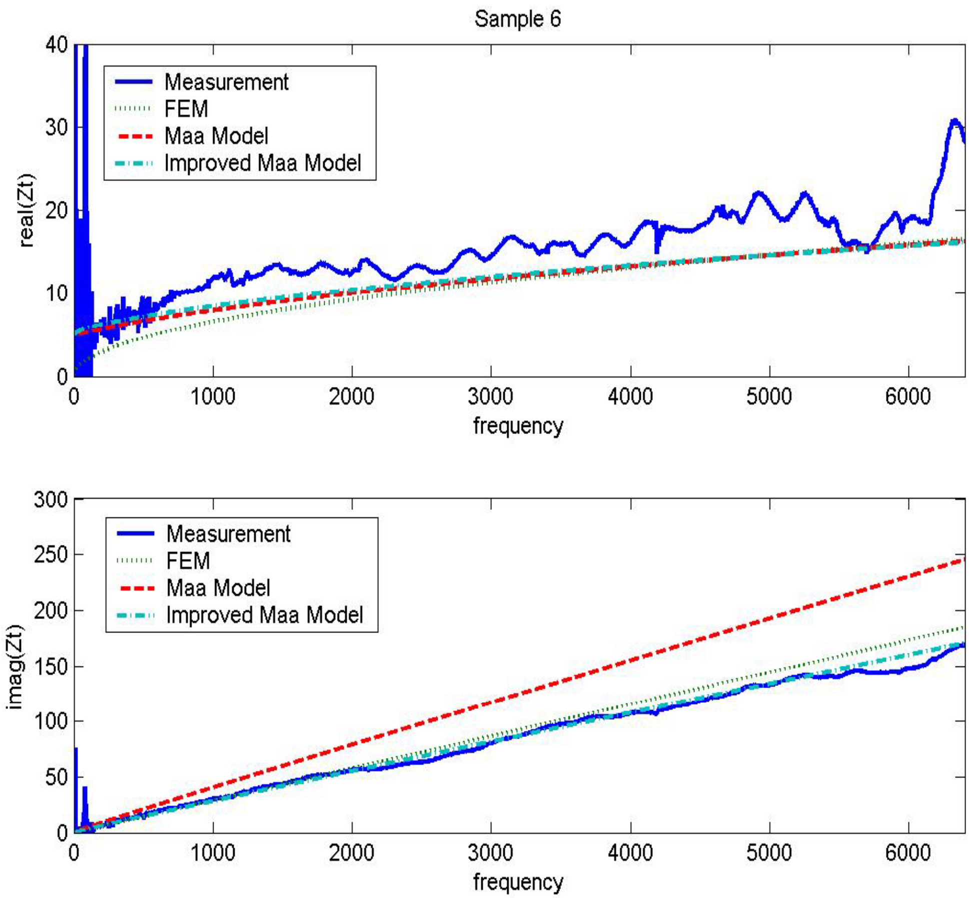
Results-High Perforation Rate



- Maa model overestimates the reactance due to neglect of hole interaction

- Improved Maa Model gives the best match with experimental results

Conclusion

- Analytical, numerical and experimental results for micro-perforated brass panels were compared
- An improved Maa model was proposed to take into account hole interactions and modification of end corrections
- An improved impedance tube measurement was set to give more accurate experimental results

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Future Work

- Further experiment should be taken to correct the equivalent tortuosity in the FEM model
- It's possible to use FEM to take into account the flexural vibration of MPP
- FEM model also has the potential to be used in the complicated structures