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Optimization of Multi-Layer Microperforated Systems for Absorption and Transmission Loss

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Advancing the Technology and Practice of Noise Control Engineering

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HERRICK LABORATORIES
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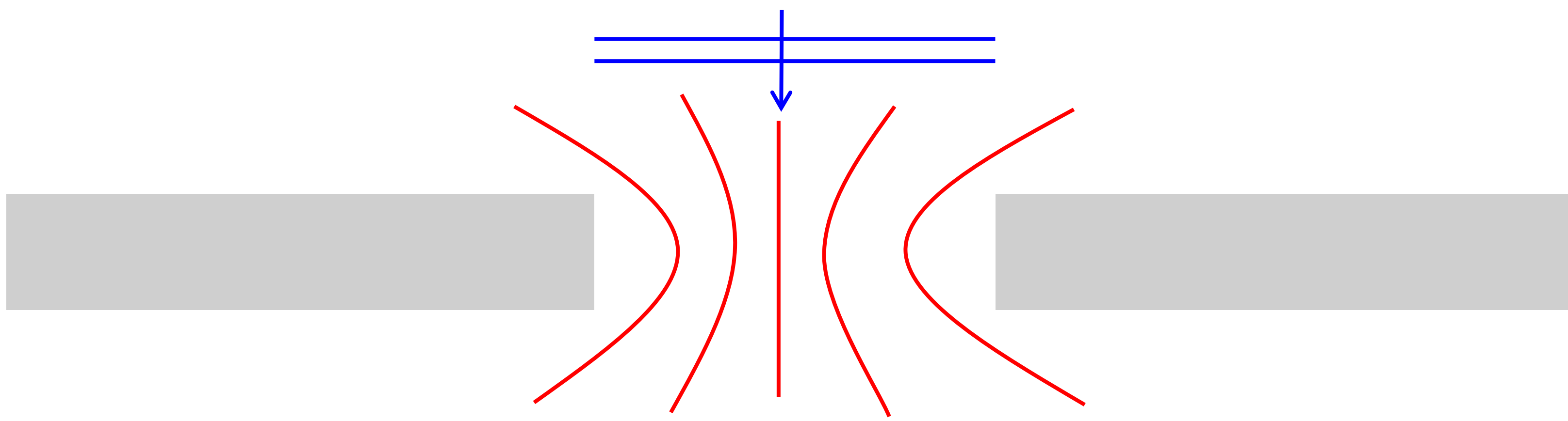
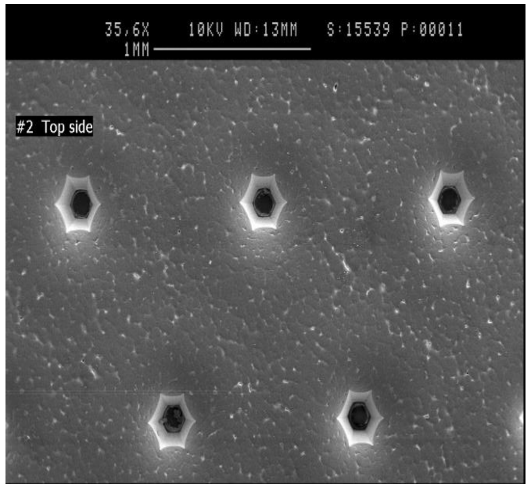
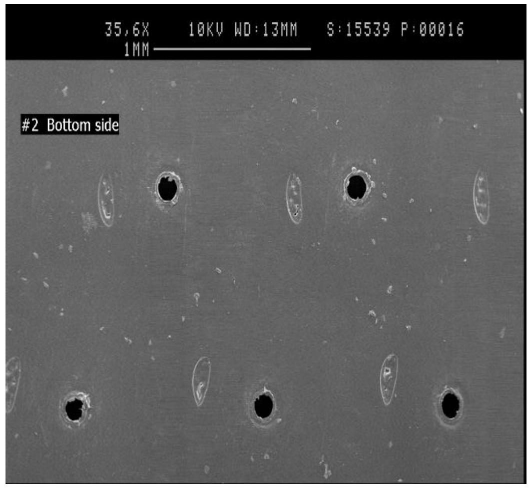
Introduction

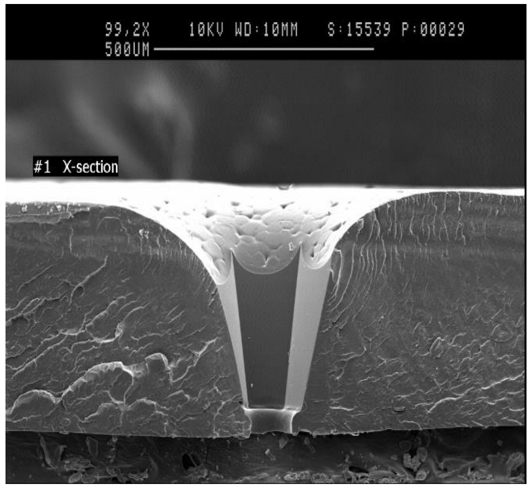
- Microperforated Panel:
  Thin film with 100 microns scale holes



- Clean, light → one of alternative to fibrous sound absorbing material







Introduction

- Acoustic Properties are controlled by:
  1. Thickness of the panel
  2. Diameter of the hole
  3. Porosity
  4. Mass per unit area
  5. Air cavity depth

- By appropriate choice of these parameters, single panel can provide good acoustic performance in one or two octave band, but not in broader range.

  ➡ Multiple-Layer Microperforated Panels are needed

- Multi-layer microperforated panels can make sound material, like functional absorber and barrier, lighter.

Introduction

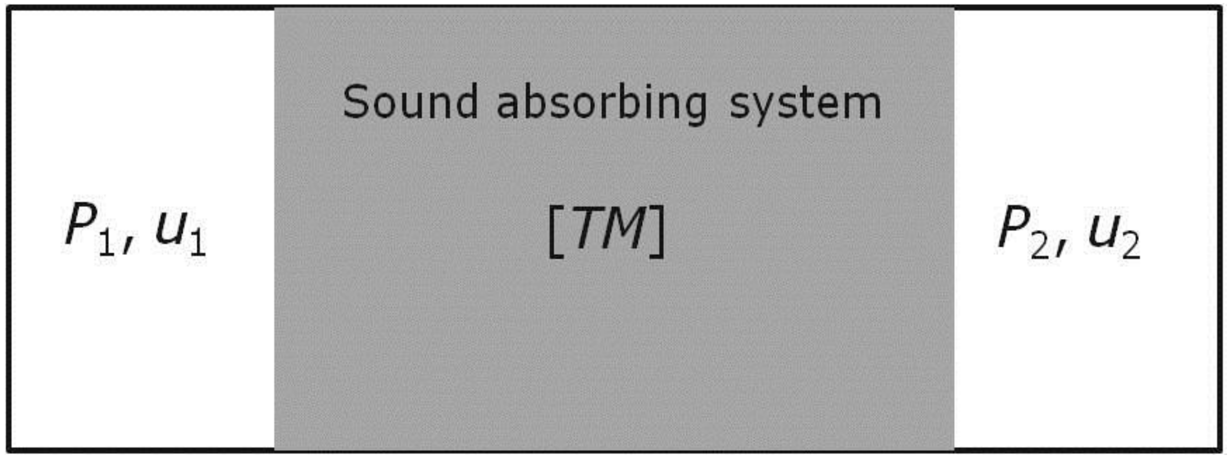
- Functional absorber

- Maximizing dissipation coefficient

- Barrier

- Maximizing Transmission loss

Transfer Matrix Method



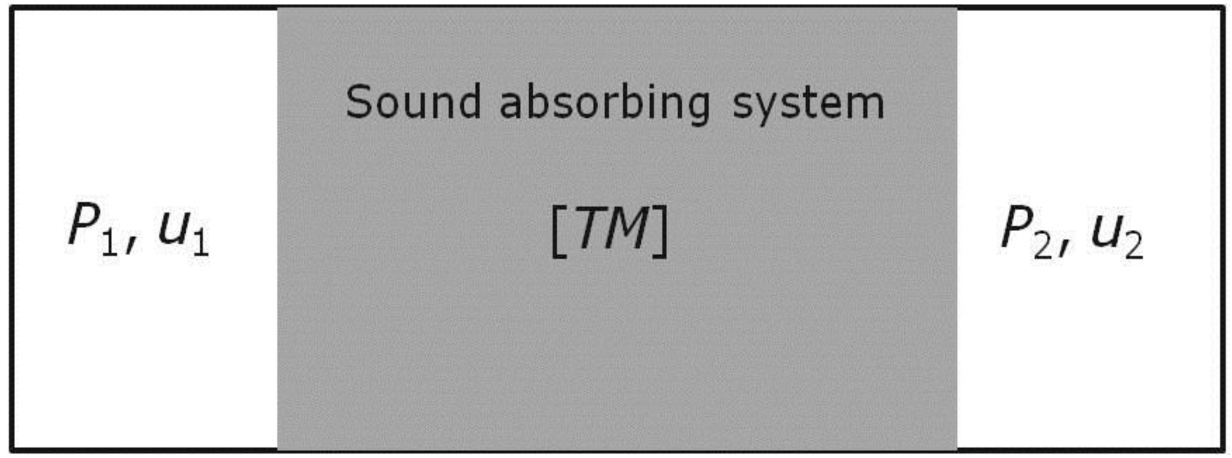
$$\begin{bmatrix} P_1 \\ u_1 \end{bmatrix} = \begin{bmatrix} TM_{11} & TM_{12} \\ TM_{21} & TM_{22} \end{bmatrix}_{total} \begin{bmatrix} P_2 \\ u_2 \end{bmatrix} = [\mathrm{TM}]_1 [\mathrm{TM}]_2 [\mathrm{TM}]_3 \cdots [\mathrm{TM}]_\mathrm{n} \begin{bmatrix} P_2 \\ u_2 \end{bmatrix}$$

$$\Gamma = \frac{TM_{11}^{total} + TM_{12}^{total}(\cos\theta/\rho c) - (\rho c/\cos\theta)TM_{21}^{total} - TM_{22}^{total}}{TM_{11}^{total} + TM_{12}^{total}(\cos\theta/\rho c) + (\rho c/\cos\theta)TM_{21}^{total} + TM_{22}^{total}}$$

$$\tau = \frac{2e^{j\frac{\omega}{c}\cos\theta L}}{TM_{11}^{total} + TM_{12}^{total}(\cos\theta/\rho c) + (\rho c/\cos\theta)TM_{21}^{total} + TM_{22}^{total}}$$

$$\overline{\alpha_d} = \frac{\int_0^{\pi/2} \alpha_d(\theta)\sin(\theta)\cos(\theta)\,d\theta}{\int_0^{\pi/2} \sin(\theta)\cos(\theta)\,d\theta} \quad \bar{\tau} = \frac{\int_0^{\pi/2} \tau(\theta)\,sin(\theta)\,cos(\theta)\,d\theta}{\int_0^{\pi/2} sin(\theta)\,cos(\theta)\,d\theta}$$

Transfer Matrix Method



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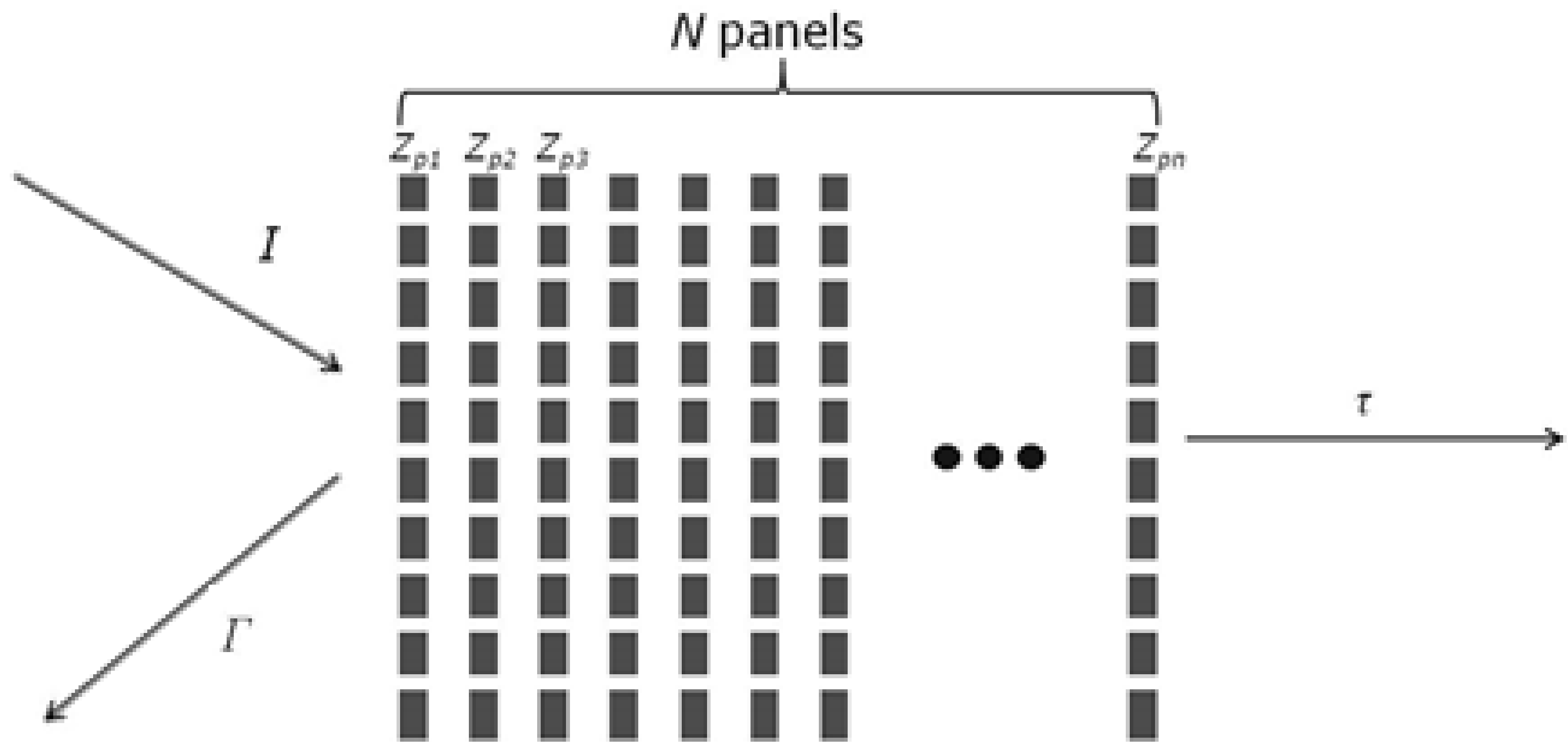
Transfer Matrix Method



$$[TM]_{total} = [TM]_{mpp1}[TM]_{air1}[TM]_{mpp2}[TM]_{air2} \cdots [TM]_{mppN}$$

$$[TM]_{air} = \begin{bmatrix} cos\,(\omega l/c) & j\rho c sin(\omega l/c) \\ (j/\rho c) sin\,(\omega l)/c) & cos\,(\omega l/c) \end{bmatrix}$$

$$[TM]_{mpp} = \begin{bmatrix} 1 & Z_{mpp} \\ 0 & 1 \end{bmatrix}$$

Microperforated panel

- Guo Model

$$R = \left(Re\left\{ \frac{j\omega t}{\sigma c}\left[1 - \frac{2}{k\sqrt{-j}}\frac{J_1(k\sqrt{-j})}{J_0(k\sqrt{-j})} \right]^{-1} \right\} + \frac{\alpha 2R_s}{\sigma\rho c} \right) \times \rho c$$

$$k = d\sqrt{\frac{\omega\rho_0}{4\eta}} \quad R_s = \frac{\sqrt{2\omega\rho_0\eta}}{2}$$

$\alpha = 4$ when sharp end

- Previous work
  - adjusted α by CFD calculation

$$\alpha = (16.9\frac{t}{d} + 152.8)f^{-0.5}$$

Microperforated panel

- Continuity and Force equilibrium

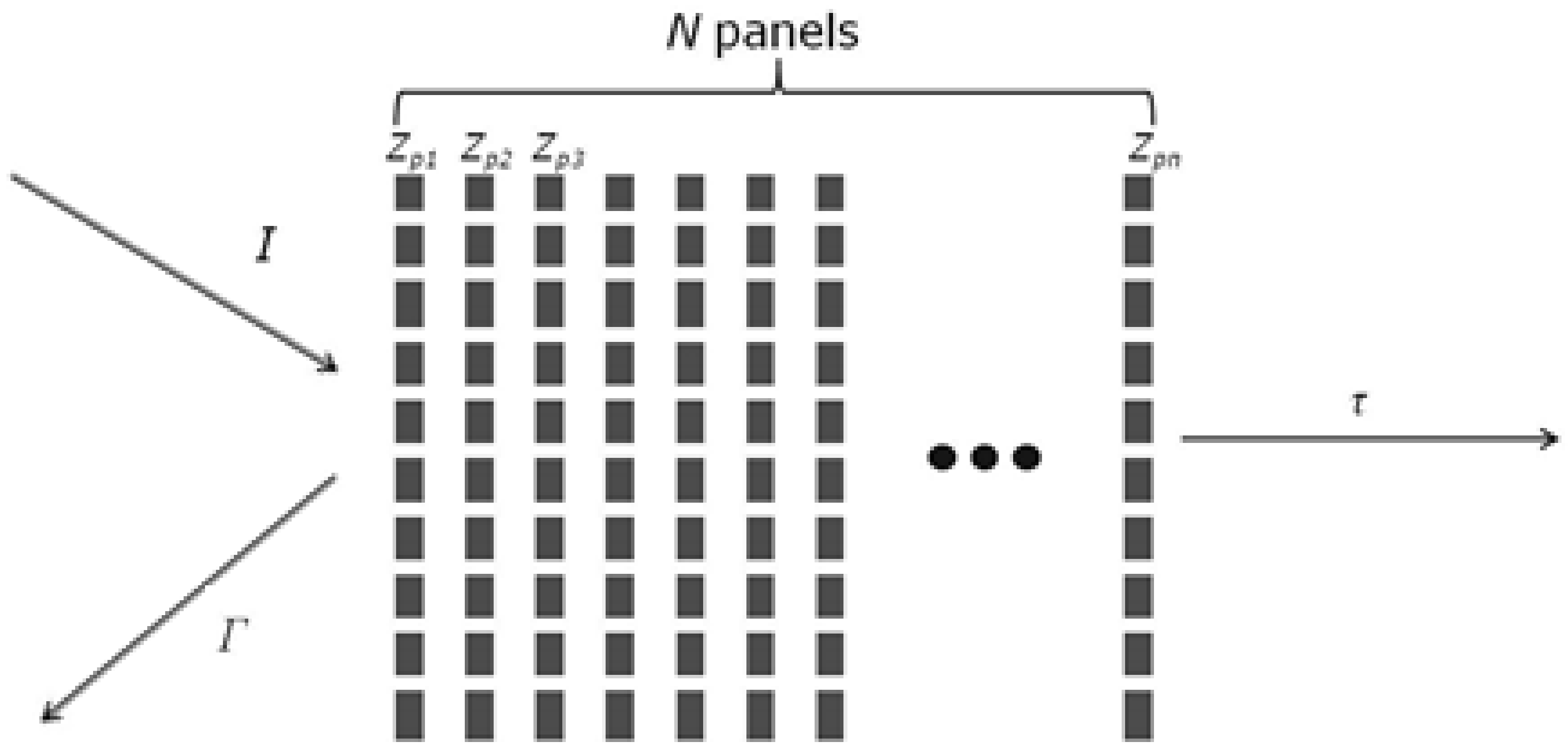
$$v_y = (1 - \sigma)v_s + \sigma v_f$$

$$P_1 - P_2 + \left(v_f - v_s\right)R\frac{\sigma^2}{1 - \sigma} = j\omega m \mathrm{v_s}$$

$$P_1 - P_2 + \left(v_f - v_s\right)R\sigma = \rho h_p j\omega \mathrm{v_f}$$

$$Z_{mpp} = \frac{R\sigma(1 - \sigma)(j\omega m - j\omega\rho(t + 2\delta)) + j\omega\rho(t + 2\delta)\{j\omega m(1 - \sigma) + R\sigma\}}{\sigma(1 - \sigma)(R + j\omega m) + (1 - \sigma)^2\rho(t + 2\delta)j\omega + \sigma^2 R}$$

Optimization



- Assumption
  - Hole of the MPP is cylindrical and sharp edged.
  - Flexural stiffness of the panel can be ignored.
  - Only locally reaction case considered.

Optimization

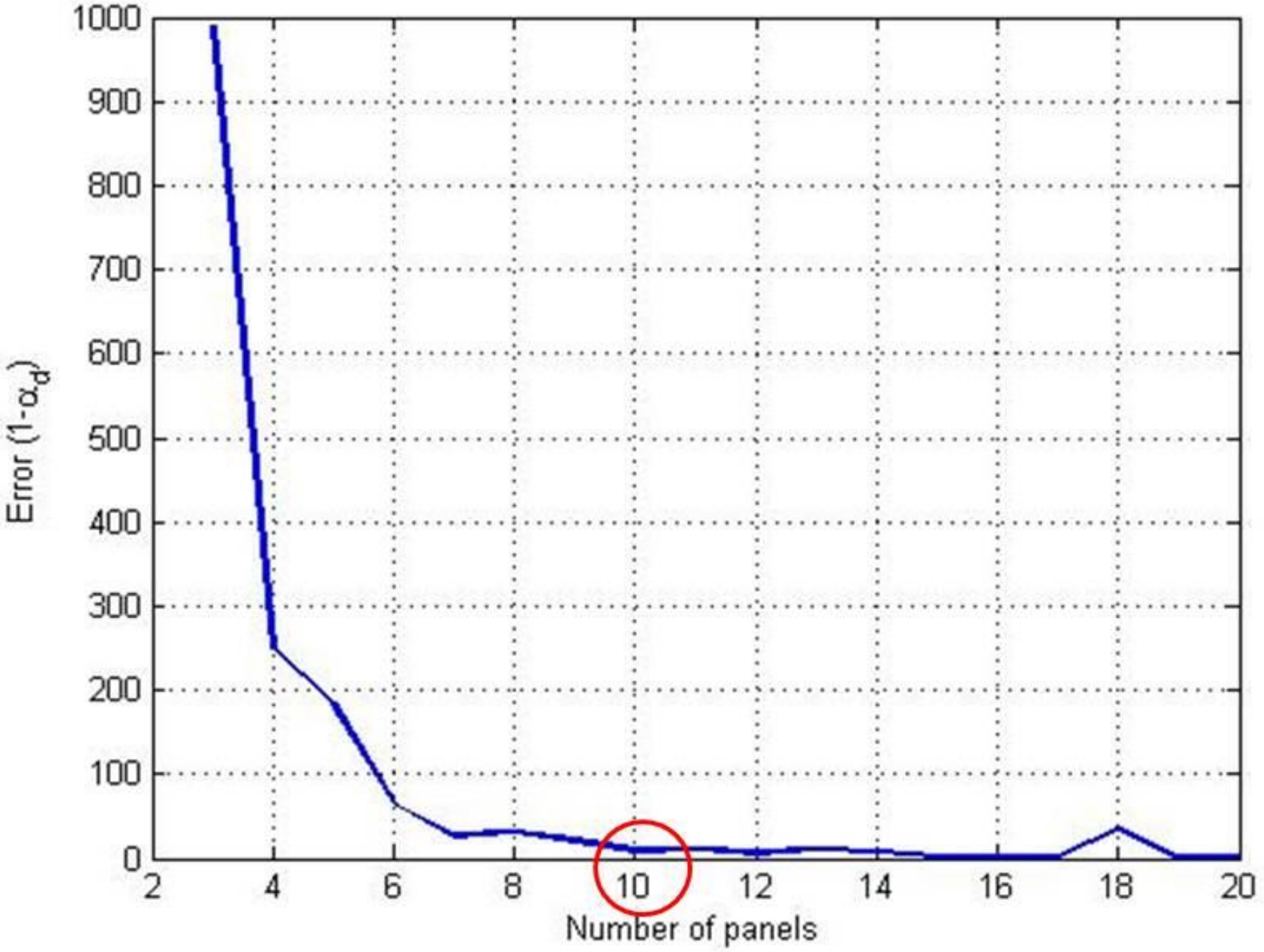
- Constraints

	Minimum	Maximum
N	2	20
t [mm]	0.2	0.8
d [mm]	0.1	0.3
σ	0.01	0.2
m [kg/m^2]	0.1	0.8
l [m]	0.001	0.2
M [kg/m^2]		3
L [m]		0.5

- Genetic Algorithm was used for optimization

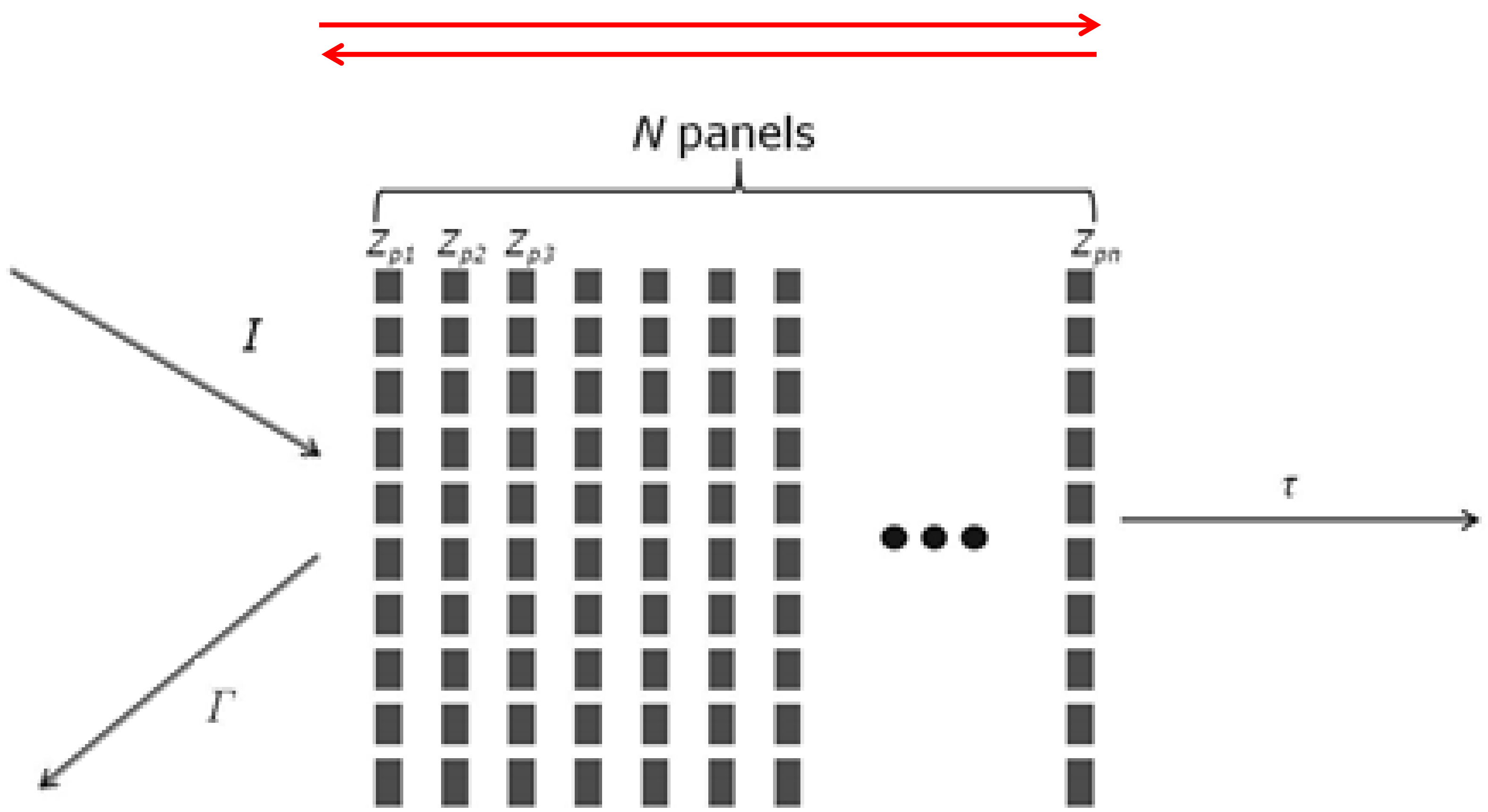
Optimization for absorption

- The number of panels



- For the error function, $1\text{-}\alpha_d$ was used in 500 to 4000 Hz.

Optimization for absorption

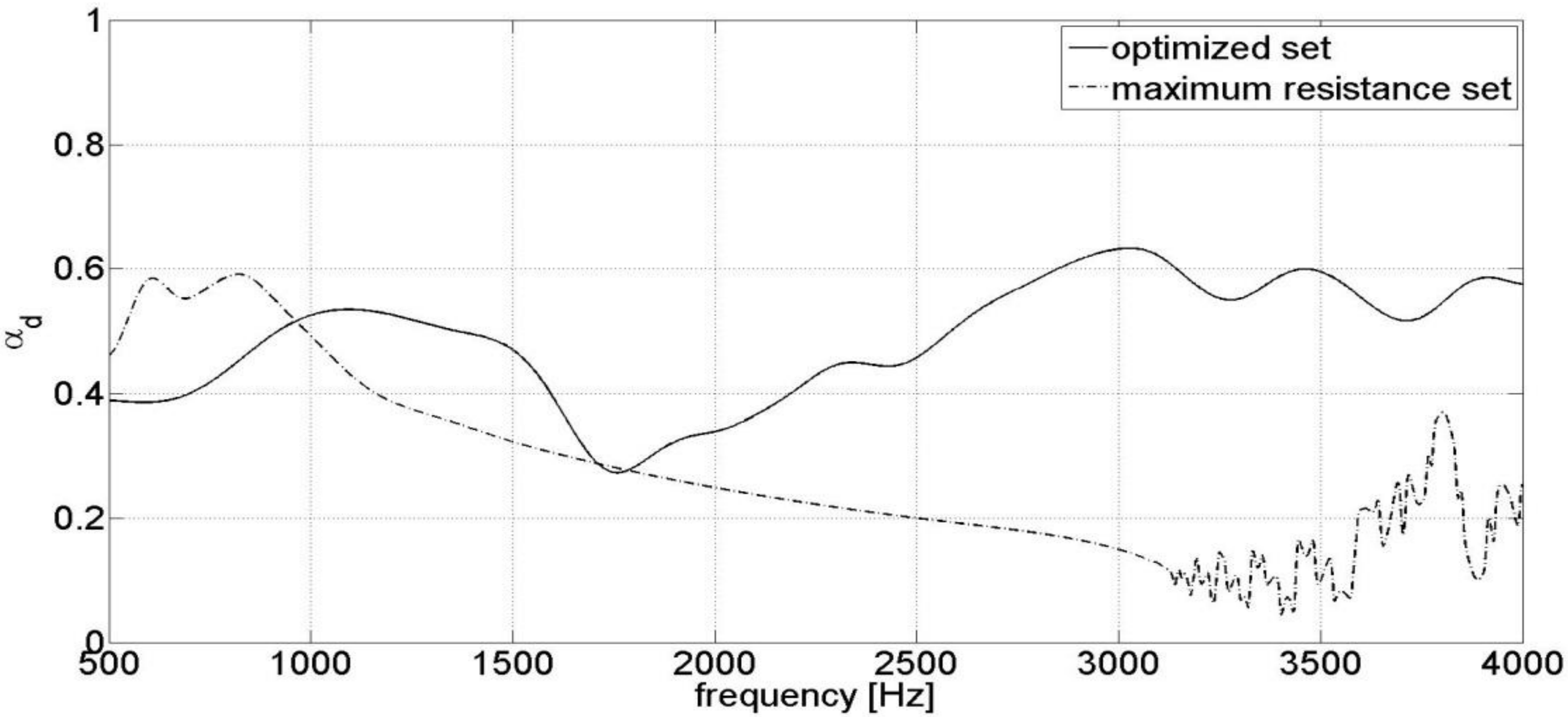


- Both direction
- Maximize averaged dissipation coefficient

Optimization for absorption

	Thickness [mm]	Diameter [mm]	Porosity	Mass per unit area [kg/m2]	Distance to next panel [m]
Panel 1	0.222	0.100	0.137	0.714	0.001
Panel 2	0.200	0.300	0.089	0.100	0.001
Panel 3	0.200	0.300	0.137	0.100	0.100
Panel 4	0.200	0.100	0.012	0.100	0.123
Panel 5	0.202	0.300	0.137	0.100	0.002
Panel 6	0.251	0.100	0.075	0.719	0.017
Panel 7	0.224	0.100	0.084	0.244	0.005
Panel 8	0.200	0.300	0.073	0.101	0.123
Panel 9	0.251	0.300	0.137	0.719	0.123
Panel 10	0.205	0.300	0.073	0.101	-

Optimization for absorption

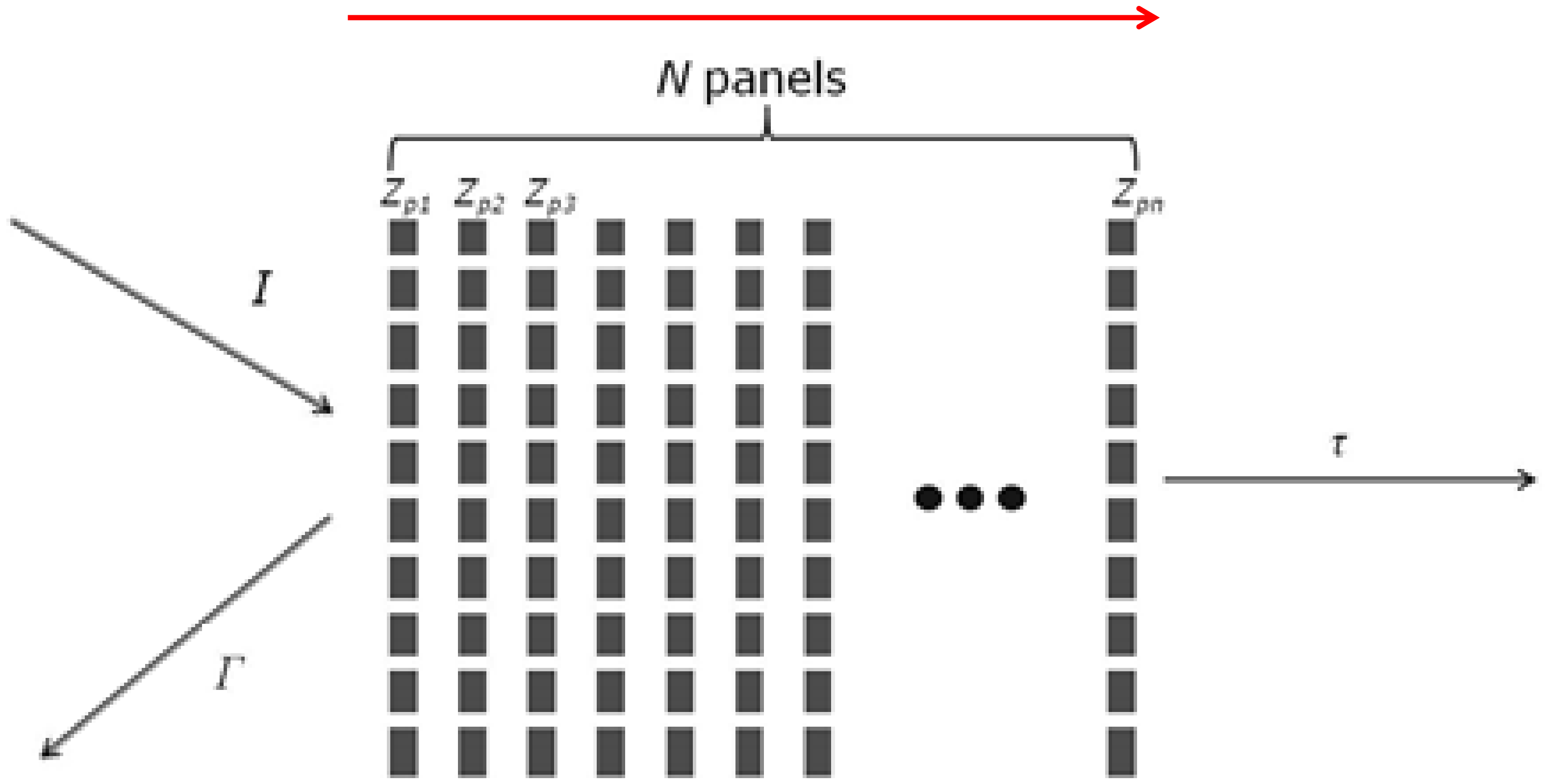


• To compare optimized set, maximum resistance set was used.

• Maximum resistance set has same distance between panels, and same panel to make flow resistance maximum.

• The optimized set provides a much higher sound dissipation coefficient in the overall speech interference range

Optimization for Transmission loss

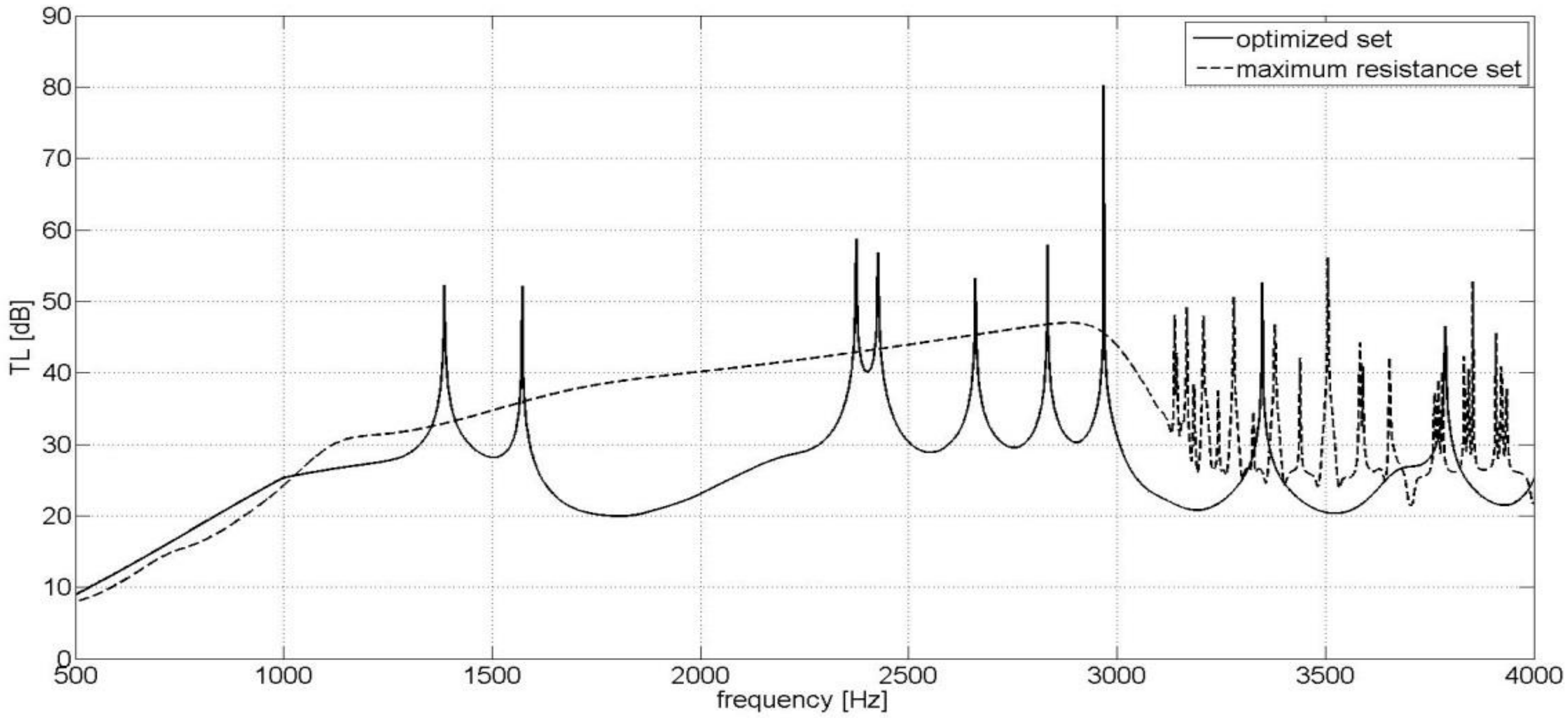


- One direction
- Maximize transmission loss

Optimization for Transmission loss

	Thickness [mm]	Diameter [mm]	Porosity	Mass per unit area [kg/m2]	Distance to next panel [m]
Panel 1	0.200	0.101	0.073	0.100	0.123
Panel 2	0.200	0.100	0.200	0.693	0.001
Panel 3	0.200	0.104	0.026	0.100	0.001
Panel 4	0.200	0.100	0.138	0.602	0.123
Panel 5	0.200	0.178	0.010	0.693	0.001
Panel 6	0.200	0.100	0.010	0.100	0.123
Panel 7	0.200	0.100	0.020	0.100	0.001
Panel 8	0.200	0.100	0.138	0.100	0.123
Panel 9	0.200	0.100	0.088	0.100	0.001
Panel 10	0.200	0.101	0.138	0.411	

Optimization for Transmission loss



- To compare optimized set, maximum resistance set was used.

- Maximum resistance set has same distance between panels, and same panel to make flow resistance maximum.

- Improved in low frequency range, but need to make smooth

Conclusion

• An appropriate combination of microperfoated panels can provide excellent performance for sound absorption.

• This suggests that a layered array of MPPs proper could be used to provide dissipation in a space

• Future work:
  • Make smooth for TL
  • Extend to the extended reaction case