Effects of acoustic scattering on the active control of noise through apertures

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Introduction: In the multi-pronged approach to tackle urban noise pollution, several active noise control (ANC) methods have been proposed and developed for the receiver-end, as shown in Fig. 1. The interest in the application of ANC on domestic windows has raised several questions on the dilemma between practicality and functionality. The quantity and physical arrangement of active control sources (usually loudspeakers) within the aperture is one such dilemma, which has to be addressed. This problem is further complicated by the scattering effects introduced by the window, such as by the frame and the glass panels.

(a) (b)

Figure 1. (a) Proposed acoustic window based on the active noise control concept. (b) Acoustic window prototype designed in Nanyang Technological University.

Computational Methods: The physical limits of the active control system can be evaluated by comparison with the passive attenuation of a fully-glazed window. A two-dimension model enclosed by a perfectly matched layer is designed to evaluate the ideal attenuation performance of both the passive and active components of the whole setup, as shown in Fig. 2.

The plane wave background radiation is initiated only in the left-half of the model (before the rigid wall) and in the positive x-direction. A glass panel is rigidly attached to the wall and has speed of sound, c_{glass} of 5585 ms^{-1}, and density, ρ_{glass} of 2180 kgm^{-3}. Attenuation performance is evaluated in terms of the sound power transmission loss (TL). The TL of the fully-glazed is given by

$$TL_{FG} = 10\log_{10}\frac{\mathbf{p}_{FG}^{H}\mathbf{p}_{FG}}{\mathbf{d}^{H}\mathbf{d}}, \qquad (1)$$

where $\mathbf{d}$ is the vector of complex pressure values at the far-field arc without the glass panel, $\mathbf{p}_{FG}$ is the vector of complex pressure values at the arc when the window is fully-glazed (L_g=L).

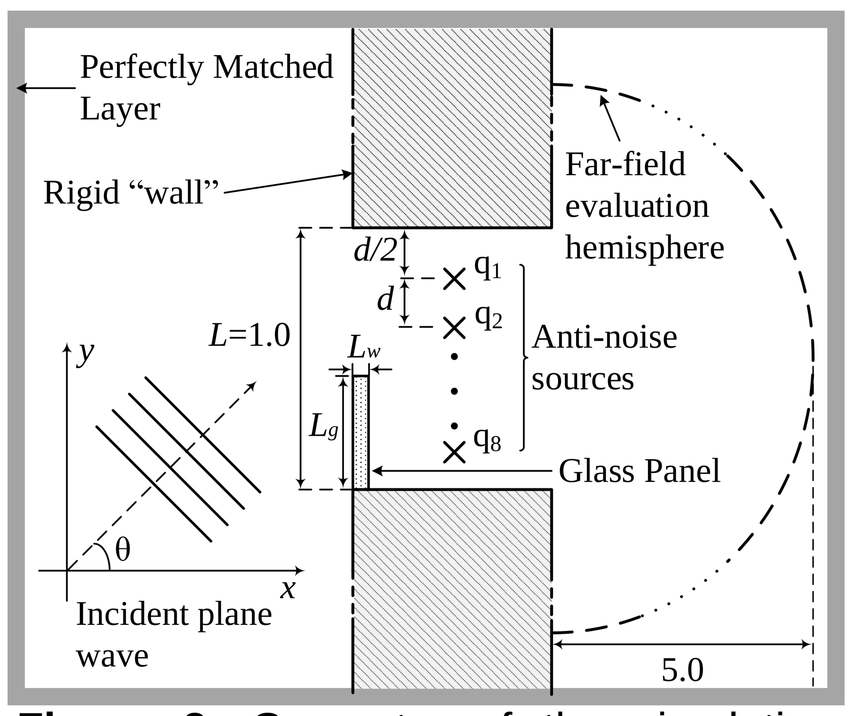

Figure 2. Geometry of the simulation model

The active control formulation is based on the minimization of the sum-of-squared pressures in the far-field [1, 2, 3]. The resultant optimal source strength is represented by its volume flow rate per unit length, written as

$$\mathbf{q}_s = -(\mathbf{G}^{H}\mathbf{G} + b\mathbf{I})^{-1}\mathbf{G}^{H}\mathbf{d}, \qquad (2)$$

where $\mathbf{G}$ is the matrix of transfer functions between each secondary source position and each point on the far-field arc, and β is the regularisation parameter that minimises ill-conditioning [2]. The attenuation performance of the ANC system is similarly determined by

$$TL_{L_g,ANC} = -10\log_{10}\frac{\mathbf{e}^{H}\mathbf{e}}{\mathbf{d}^{H}\mathbf{d}}, \qquad (3)$$

where $\mathbf{e}$ is the vector of complex pressure values after control, and L_g is the size of the glass panel.

Results: The transmission loss of a fully glazed window corresponds well to measured data for both acoustic pressure and acoustic-structure interaction modes, as shown in Fig. 3.

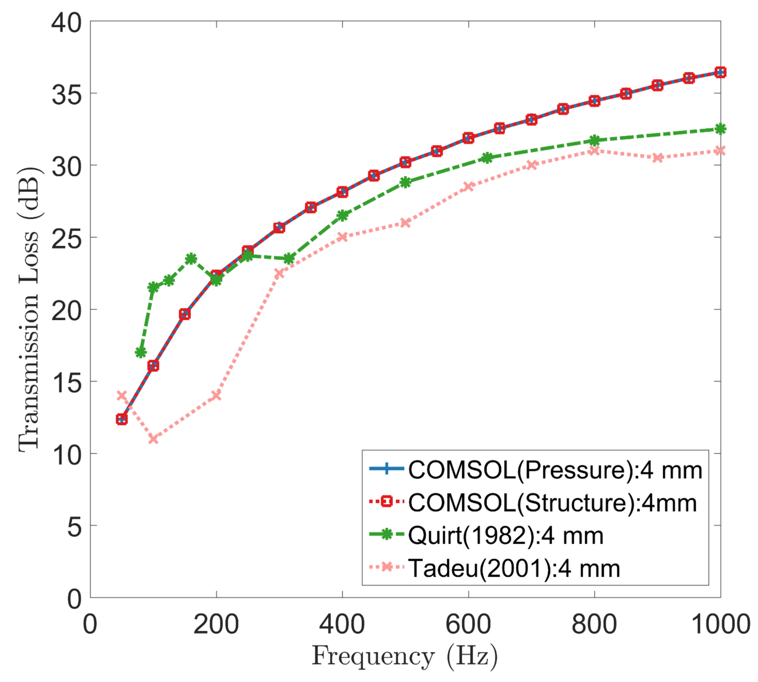

Figure 3. Transmission loss of a fully glazed, 4 mm thick glass panel as compared to Quirt and Tadeu.

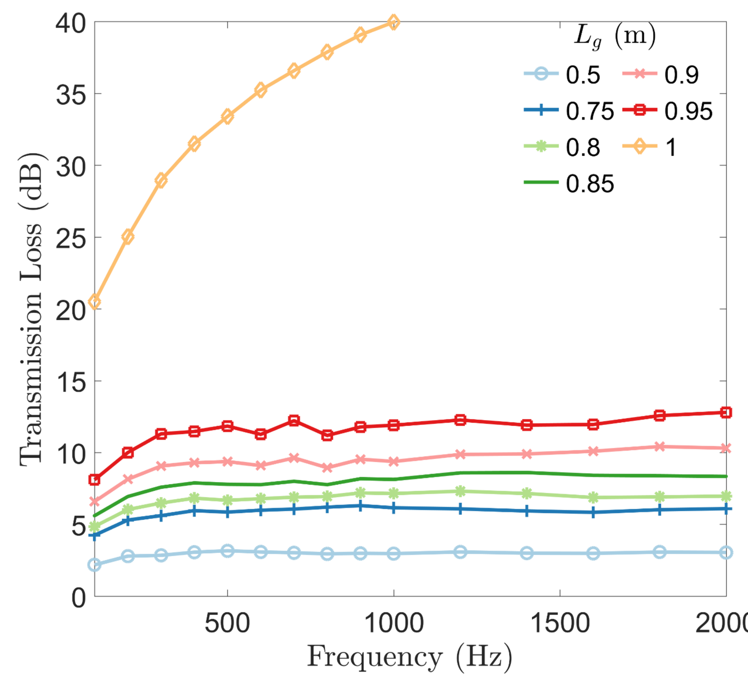

Figure 4. Transmission loss of a 6 mm thick glass panel at different L_g, at 0º noise incidence.

The passive attenuation provided by the glass panel degrades drastically once the window is not fully glazed. The attenuation also becomes rather uniform across frequencies up to 2 kHz when it is not fully glazed, as shown in Fig. 4. This suggests that there is a potential for an ANC system to provide attenuation up to or exceeding the performance of a fully glazed window, while still allowing natural ventilation due to partial glazing.

When the aperture is 90% glazed (L_g = 0.9 m), only two sources at positions q_1 and q_2 in Fig. 2 is required to achieve similar transmission loss as the fully glazed window, as depicted in Fig. 5. Similarly, three sources are sufficient at 75% glazing, when d is 0.125 m, as shown in Fig. 6.

The sound pressure distribution before and after active control when the noise source is 1000 Hz at 0º incidence is illustrated in Fig. 7. Global control is attained with three sources for a noise source of 90 dB.

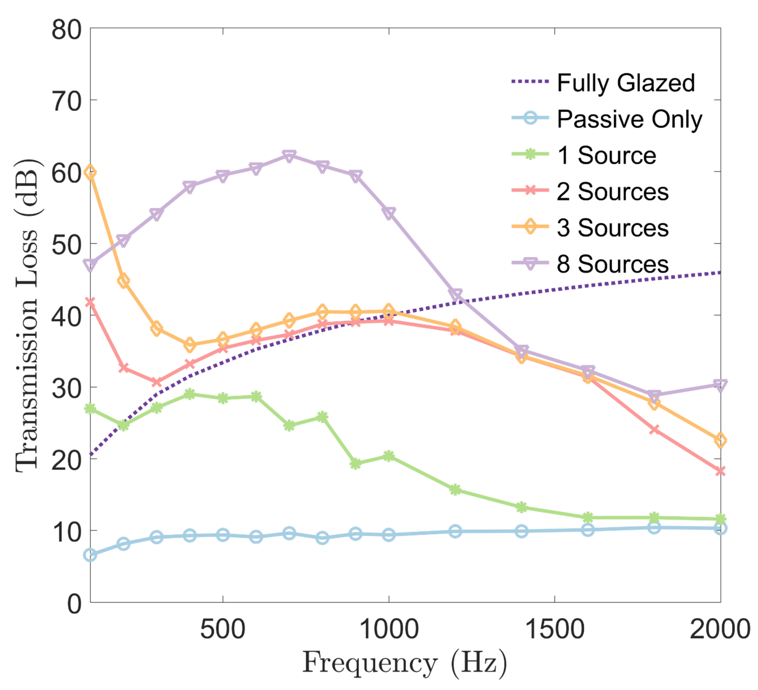

Figure 5. Transmission loss of different source configurations when L_g = 0.9 m at 0º noise incidence.

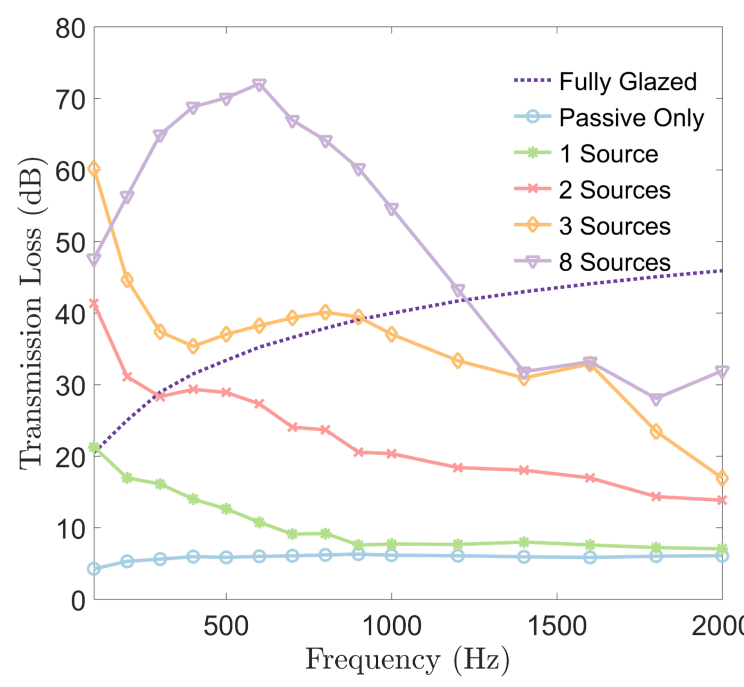

Figure 6. Transmission loss of different source configurations when L_g = 0.75 m at 0º noise incidence.

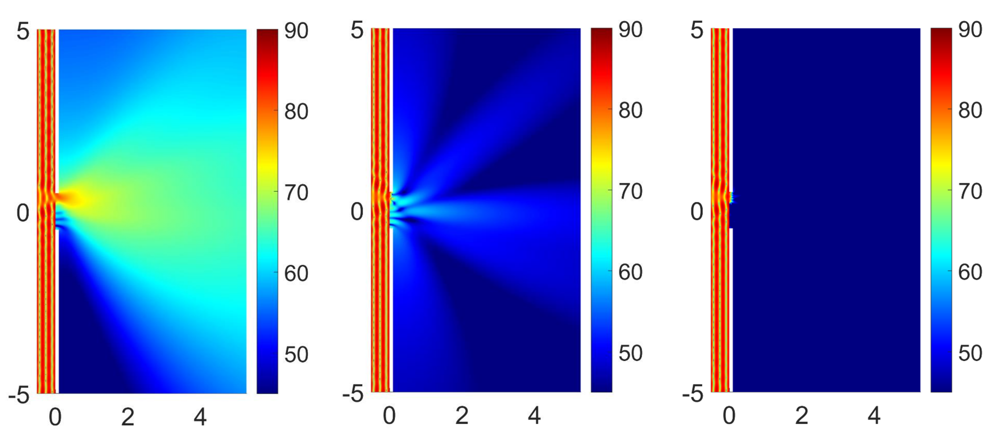

Figure 7. Sound pressure distribution without ANC (left), with two sources (middle), and three sources (right) at 1000 Hz, with 75% glazing.

Conclusions: The results have demonstrated that an array of active control sources purposefully distributed across an aperture is a potential technique that can control noise while still maintaining natural ventilation. Attenuation performance does not seem to be affected by the presence of the glass panel. However, presence of the glass panels can potentially reduce attenuation performance by affecting the quality of the reference signals during practical implementation.

References:
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