Periodicity-induced noise reduction effects by barriers

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Noise barriers reduce the level of noise that reaches the receiver by interrupting the noise propagation path. Even though noise barriers are effective at high frequencies, low-frequency control remains challenging as sound waves at low frequencies are easily diffracted over the barriers. In this work, we show that the diffracted wave around the barrier can be utilized to enhance the attenuation performance of the noise barrier at low frequencies. Unlike the previous works using sonic crystals [1,2,3], the resonators are periodically arranged along the direction perpendicular to the ground, as shown in Fig. 1(a). To evaluate the noise reduction performance of the barrier, numerical simulations based on the finite element method were conducted. Figure 1(b) presents the insertion loss of the noise barrier in the frequency range of 100-500 Hz. The graph shows that the attenuation is significantly increased when using a periodic array of resonators as opposed to the nominal case.

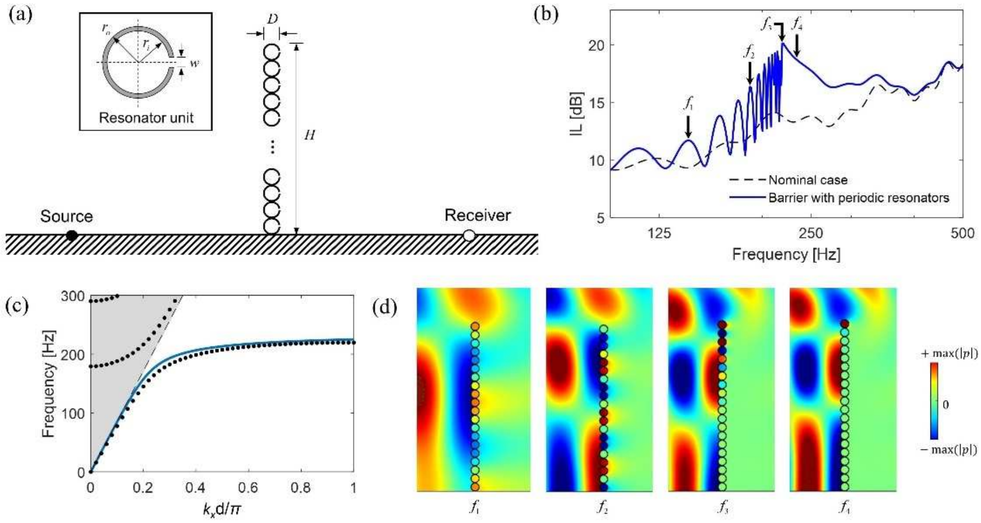

Figure 1. (a) Geometric configuration of the noise barrier comprised of periodic resonators. A zoomed view of the resonator unit is shown in the black-lined box. (b) Insertion loss by the barrier with periodic resonators (blue line) compared with the one by a nominal noise barrier (black dashed line). (c) Dispersion curve of the acoustic waves propagating above the periodic resonators. (d) Acoustic pressure fields around the noise barrier with periodic resonators at frequencies f_1, f_2, f_3, and f_4 denoted in (b).

The physical mechanism of the observed increase in insertion loss can be explained by analyzing wave behavior around the noise barrier. The periodic resonators change the propagation characteristic of the sound waves along the noise barrier. Previously it was reported that when a sound wave propagates along a horizontal periodic structure comprised of a resonator unit, a guided mode is generated on the surface [4,5]. Figure 1(c) shows the dispersion curve of the periodic structure. For small values of k_x, the dispersion of the guided mode follows that of the sound line, but when k_x increases, the frequency converges to the resonance frequency of the resonator.

Figure 1(d) shows the acoustic pressure fields around the noise barrier at selected frequencies. From the pressure fields at f_1 and f_2, we see that the waves show the pattern of the guided mode confined at the surface of the resonators. Another noticeable thing is that these wave patterns are the ones of standing wave patterns along with the height of the noise barrier, which indicates that the multiple peaks below the resonance frequency are due to combined effects of the guided mode generated by the nature of the periodic resonators and the standing wave modes around the noise barrier. Unlike the standing wave patterns shown at f_1 and f_2, the pressure distribution at and above the resonance frequency (f_3 and

f_4) shows wave behaviors that appear in the resonance gap of the sonic crystals. In this resonance gap, sound energies are highly concentrated in the first few unit cells along the direction of the wave propagation and do not transmit any further. Especially at f_4, it is observed that the waves interact only with the first resonator located at the top of the noise barrier. As the sound energies are localized at the resonators, the sound energy transmitted through the noise barrier can be significantly reduced. It should be noted that the physical origins of the sound attenuation at the frequencies below (f_1 and f_2) and above the resonance frequency (f_3 and f_4) show distinctive behaviors. The waves below the resonance are propagating guided modes along with the periodicity of the structure, whereas the waves above the resonance have evanescent nature.

This research demonstrates that vertical periodic structures can be used to control diffracted waves around the noise barrier and be designed in such a way that they reduce low-frequency noise transmission. Future work may include further tuning the resonator unit to desired specifications, adding top edges (e.g., T- or Y-profiles), and investigating the influence of ground impedance and meteorological conditions.

References

[1] Sánchez-Pérez, J. V.; Rubio, C.; Martinez-Sala, R.; Sanchez-Grandia, R.; Gomez, V. Acoustic barriers based on periodic arrays of scatterers, *Applied Physics Letters*, 81(27), 5240-5242, 2002.

[2] Castiñeira-Ibáñez, S.; Rubio, C.; Sánchez-Pérez, J. V. Acoustic wave diffraction at the upper edge of a two-dimensional periodic array of finite rigid cylinders. A comprehensive design model of periodicity-based devices, *Europhysics Letters*, 101(6), 64002, 2013.

[3] Thota, M.; Wang, K.W.; Reconfigurable origami sonic barriers with tunable bandgaps for traffic noise mitigation, *Journal of Applied Physics*, 112, 154901, 2017.

[4] Zhu, J.; Chen, Y.; Zhu, X.; Garcia-Vidal, F. J.; Yin, X.; Zhang, W.; Zhang, X. Acoustic rainbow trapping, *Scientific Reports*, 3, 1728, 2014.

[5] Maznev, A.; Gu, G.; Sun, S.; Xu, J.; Shen, Y.; Fang, N.; Zhang, S. Extraordinary focusing of sound above a soda can array without time reversal, *New Journal of Physics*, 17(4), 042001, 2015.