

Novel compact meta-silencer design leverages acoustic black hole and rainbow trapping effects

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Harnessing Acoustic Black Holes and Rainbow Trapping in Coiled *Meta*-Silencers for Effective Noise Control

Acoustic silencers are utilized in automobiles, factories, aircraft, and various other settings to mitigate noise

However, conventional silencers often require bulky designs to achieve effective low-frequency noise reduction

Novel coiled-multi-slit *meta*-silencer

Meta-silencer geometry

Resonator

Low-frequency noise reduction at zero group velocity

Methods for assessing the performance of the *meta*-silencer

- Transfer matrix method
- Finite element method
- Experimental validation using an impedance tube

Efficient low frequency noise mitigation with compact size

Performance of *meta*-silencer array

- ✓ Operates across a broad bandwidth above 728 Hz
- ✓ Broadband STL is +7dB higher (vs. single silencer)
- ✓ Max absorption coefficient > 0.5 (single silencer limit)

STL: sound transmission loss

The proposed coiled multi-slit design of the *meta*-silencer establishes a foundation for developing miniaturized, high-efficiency silencers aimed at effectively reducing low-frequency noise

Enhanced acoustic attenuation in a coiled *meta*-silencer: Broadband low-frequency noise control through rainbow trapping
 Lee et al. (2024) | Mechanical Systems and Signal Processing | DOI: 10.1016/j.ymsp.2024.111744

Website: <https://sites.google.com/view/mwavelab/our-lab>
 PUSAN NATIONAL UNIVERSITY

Pusan National University researchers developed a novel *meta*-silencer that reduced broadband low-frequency noise by leveraging the acoustic black hole and rainbow trapping effects, resulting in compact and efficient systems for low-frequency noise reduction. Credit: Kyungjun Song from Pusan National University, Korea

Chronic low-frequency noise from vehicles, appliances, and industries takes a toll on mental health, causing stress and anxiety. Traditional acoustic silencers require bulky designs to achieve effective noise reduction at low frequencies.

Recent advances in acoustic metamaterials utilize the slow-wave effect and have shown promise for reducing low-frequency noise with more compact designs. Notable among them are devices capable of generating acoustic black holes (ABH) continuously slowing down [sound waves](#) until their velocities reach zero. Another alternative is acoustic rainbow trapping (RT), where sound waves are confined to specific paths within a structure, separating and trapping different frequencies at distinct locations.

Leveraging these effects, a research team from Pusan National University in South Korea, led by Professor Kyungjun Song of the Department of Mechanical Engineering, developed an innovative coiled meta-silencer.

"Our meta-silencer features a compact design with four parallel resonators, each containing a coiled multi-slit that utilizes the ABH and RT mechanisms for efficient low-frequency noise reduction," explains Prof. Song. Their study is [published](#) in the *Mechanical Systems and Signal Processing* journal.

The meta-silencer design features four resonators placed in parallel around a cubical waveguide. Each resonator consists of three sections: an internal cavity, a multi-slit, and an inlet. The multi-slit featured slits placed at the top and bottom of the resonator in a quadratic, horn-like profile, widening at the inlet and gradually narrowing towards the cavity, progressively changing the acoustic impedance, facilitating the ABH effect.

Additionally, as frequency increases, the multi-slits act as independent resonators based on frequency, giving rise to the RT effect. Since the RT effect shows an inverse relationship between slit length and frequency, the researchers implemented a coiled-up slit design to achieve efficient RT at [low frequencies](#).

The researchers developed three different resonator designs categorized by slit length, and evaluated their performance using simulations and experimental validation. Model 1 featured straight slits, while Model 2 had a top slit 1.3 times longer and a bottom slit 0.7 times shorter than those of Model 1. Model 3 incorporated a coiled-up slit structure from the Model 2's structure.

Results showed that the meta-silencer operated in three main sound-blocking modes: a foundational plane wave mode, the multiple-slit localized mode induced by the ABH effect, and the single-slit localized mode generated by the RT effect. Incorporation of coiled-up slits in Model 3 enhanced its performance by shifting the frequency at which sound wave velocities reached zero to 728 Hz.

Additionally, it achieved an average experimental sound transmission loss (STL) of 6.73 decibel (dB) across a broad 200–1800 Hertz (Hz) band and an absorption coefficient of 0.49. The researchers also designed a dual-series array meta-silencer, comprising two meta-silencers arranged back-to-back, which nearly doubled the average STL to 13.07 dB and the maximum absorption coefficient to 0.9.

"Unlike traditional large-scale silencers, this compact meta-silencer can be directly integrated into miniaturized machines and narrow spaces, like engine compartments and machinery enclosures, providing targeted low-frequency noise reduction at the source. This technology can be applied in fields like aviation to realize quieter cabins and also reduce noise from construction, traffic, and [industrial activity](#) in [urban areas](#), making

homes quieter and improving quality of life," says Prof. Song.

"With plans for prototype development and testing already underway, we anticipate seeing the first commercial products in the market within the next 2–3 years, paving the way to quieter living and working environments."

More information: Soo-Seong Lee et al, Enhanced acoustic attenuation in a coiled meta-silencer: Broadband low-frequency noise control through rainbow trapping, *Mechanical Systems and Signal Processing* (2024). [DOI: 10.1016/j.ymssp.2024.111744](https://doi.org/10.1016/j.ymssp.2024.111744)

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