

A Transparent Waveguide for Sound

Acoustic waves can be guided through a narrow “tunnel” that lacks walls and thus presents no obstruction to sound traveling across its path.

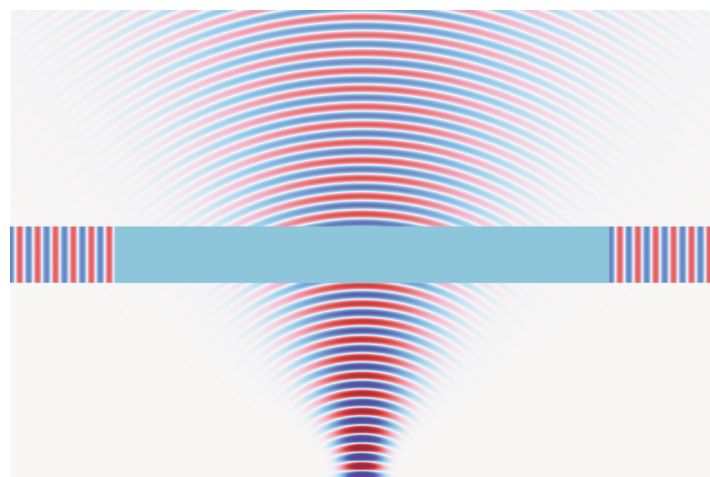
By **Mark Buchanan**

Researchers have devised a “ghost tunnel”—a nearly perfect waveguide for sound that allows other sound waves to pass across its path undisturbed [1]. The tunnel is essentially invisible to external waves. The researchers expect the 2D acoustic structure to find use in situations such as complex sonar devices, where multiple signal channels must cross without interacting.

The hard walls of metal pipes and other ordinary waveguides keep sound trapped inside, but they also present obstructions that scatter external sound waves. This scattering can be a major problem in environments such as integrated acoustic



Where the magic happens. The ghost tunnel’s physical medium was an array of 15-mm-tall, partially hollow plastic elements.
Credit: C. Xu *et al.* [1]



Acoustic pipeline. A sound wave passing through the tunnel (left to right) is trapped inside and experiences minimal loss. Yet an external wave incident on the boundaries of the tunnel experiences no obstacle and passes through as if propagating through air.
Credit: C. Xu *et al.* [1]

circuits or sonar applications, where sound waves are propagating in multiple directions outside of waveguides. These nonguided waves can potentially suffer from signal-clarity degradation.

In seeking a way around this problem, Changqing Xu of Nanjing Normal University in China and colleagues were inspired by recent advances in metamaterials—structures designed with repeating patterns smaller than the wavelength of the phenomena they influence. Such structures can have physical properties not possible with normal materials. For example, every natural material has a nonzero refractive index determined by its density and compressibility. But researchers have been able to build metamaterials in which the refractive index is zero, at least for specific frequencies. At those frequencies, the wavelength becomes infinitely long, and sound is transmitted with high fidelity.

Using this idea, Xu and colleagues sought to create a medium with unusual properties: For waves traveling through a channel region, there should appear to be walls around the channel, but

for waves traveling in the perpendicular direction originating from outside the channel, the region should look like empty space. To test the idea, they designed a ghost tunnel for sound confined to two dimensions. The structure consists of a surface with an array of 3D-printed unit cells on top, each 50×67 mm and 15 mm high, constructed from sound-reflective material. The researchers tuned the effective density and compressibility of the metamaterial and achieved an effective zero index of refraction for sound at their chosen operating frequency of 2.8 kHz.

Each cell contains two square air cavities connected to a series of intricate, coiled channels that link the central cavities to the outside air. These labyrinthine coils slow the movement of air inside the element, making the zero-index effect possible in a relatively small unit cell. By tailoring the geometry of the air cavities and coiled channels, the researchers created a material that is matched to certain acoustic properties of the outside air. This so-called impedance matching makes the channel transparent (reflection-free) for external waves crossing through the tunnel. The team expects that sound waves within a wide range of frequencies should be able to cross the tunnel without being disturbed.

Xu and colleagues conducted two primary sets of experiments to demonstrate the ghost-tunnel effect. First, sending sound into the mouth of the tunnel, they observed nearly perfect transmission: The sound stayed strictly confined within the boundaries of the tunnel and emerged from the other end with almost no loss in intensity. Second, they sent an external sound wave toward the side of the tunnel, and the wave passed

through the structure, emerging undistorted on the other side.

“This method offers a new route to overcoming key limitations of acoustic devices, such as bulky designs, limited functionality, and susceptibility to interference in complex environments,” Xu says. “Moreover,” he adds, “the generality of the approach should also make it useful for other types of waves, including photons, plasmons, and even electronic waves.”

“This is a very elegant design,” says physicist and metamaterials expert Baile Zhang of the Nanyang Technological University of Singapore. One likely immediate use, he thinks, could be in noise control. “Unlike conventional approaches that rely on blocking or absorbing sound, which typically affect all sound waves indiscriminately, this kind of structure enables spatially selective control—guiding noise along desired paths while leaving other regions essentially undisturbed.”

The researchers are eager to expand this concept beyond the laboratory. They are currently exploring how to make these ghost tunnels adjustable, so that they can be turned on and off or adapted to work across a much broader range of frequencies for the waves inside the tunnel.

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REFERENCES

1. C. Xu *et al.*, “Symmetry-protected acoustic ‘ghost tunnels,’” *Phys. Rev. Lett.* **136**, 137001 (2026).