

A three-dimensional acoustic invisibility cloak

Over the past decade, new tools have emerged that enable precise control over the propagation of electromagnetic waves, sound, and even heat. Using coordinate transformations, one can calculate the spatial variations in materials parameters, such as the dielectric constant and magnetic susceptibility or the mass density and bulk modulus, that will produce the desired propagation. Metamaterials provide a way to engineer the needed parameters from assemblies of appropriate subwavelength building blocks. (See the article by Martin Wegener and Stefan Linden, *PHYSICS TODAY*, October 2010, page 32.) But the required materials properties can be quite complex, particularly in acoustics, for which the implementations have been limited to two-dimensional configurations.

Lucian Zigoneanu, Bogdan-Ioan Popa, and Steven Cummer of Duke University have now demonstrated a 3D acoustic device, shown here, that shields its interior region from sound waves coming from any direction. A so-called ground cloak, it reflects the waves as if it were a flat surface. The pyramidal structure, 34 cm on a side, consists of 11 shingles of perforated acrylic; the size and spacing of the holes and the angle and spacing of the sheets were determined by solving the coordinate transformation equations. The 5-cm unit cell is some 20 times smaller than the wavelength at the design frequency of 3 kHz. The researchers did have to make one compromise: The exact solution called for a material less dense and more compressible than air, but such characteristics are difficult to obtain with passive metamaterials. So the team instead introduced a modest impedance mismatch. Despite that mismatch—and the cloak's discrete edges—the device replicates the angle of ideally reflected sound waves to within 15° and the amplitude to within 74%. (L. Zigoneanu, B.-I. Popa, S. A. Cummer, *Nat. Mater.*, in press.)

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