Researchers prove fundamental limits of electromagnetic energy absorption

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Electrical engineers at Duke University have determined the theoretical fundamental limit for how much electromagnetic energy a transparent material with a given thickness can absorb. The finding will help engineers optimize devices designed to block certain frequencies of radiation while allowing others to pass through, for applications such as stealth or wireless communications.

"Much of the physics of the known universe already have fundamental solutions or are too complex to get an exact answer," said Willie Padilla, professor of electrical and computer engineering at Duke. "In any field, finding a truly novel, fundamental, exact result like this is rare."

The research appears in *Nanophotonics.*

Whether building an antenna or developing sunscreen, there are many instances where certain types of light must be absorbed. One trick to maximizing that amount is increasing the thickness of the material absorbing the energy.

However, the needed thickness for a transparent material to provide that absorption was unknown till now.

More than 20 years ago, Konstantin N. Rozanov of the Institute for Theoretical and Applied Electrodynamics in Moscow, Russia, figured out the most light over a range of wavelengths that a device of a certain thickness could absorb if one side was lined with metal. This scenario creates a boundary on one side where all light either reflects back or is absorbed, providing a constraint that allows a certain mathematical approach to crack the problem.

Taking away that metal edge and allowing the light to continue through, however, is a horse of an entirely different color on the electromagnetic spectrum.

"Rozanov used a clever trick where he worked in wavelength instead of frequency," said Yang Deng, a research assistant working in Padilla's laboratory. "But several researchers have since tried using that approach to this problem and failed."

To come up with a new mathematical approach, Padilla and Deng collaborated with Vahid Tarokh, the Rhodes Family Professor of Electrical and Computer Engineering at Duke. Tarokh's research spans a wide range of topics while pursuing new formulations and approaches to getting the most out of datasets.

Tarokh was able to figure out how to shape the problem so that it could be solved, pulling a rabbit from a mathematical hat.

"Hindsight is 20/20, but even mathematicians call these creative strategies 'tricks,'" Padilla said.

Beyond the novelty of solving a long-sought-after problem, the researchers say their work has practical implications in several areas. Metal-backed absorbers won't let any type of electromagnetic energy pass through. But there are certain applications where you might want to block some frequencies while letting others pass.

For example, cellular phones might want to be able to block certain types of harmful electromagnetic radiation while letting others like GPS or Bluetooth through. Knowing the fundamental limits of this type of goal will allow engineers to know when more work optimizing their design will not be worth the effort.

More information: Willie J. Padilla et al, Fundamental absorption bandwidth to thickness limit for transparent homogeneous layers, *Nanophotonics* (2024). DOI: 10.1515/nanoph-2023-0920

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