New understanding of electromagnetism could enable 'antennas on a chip'

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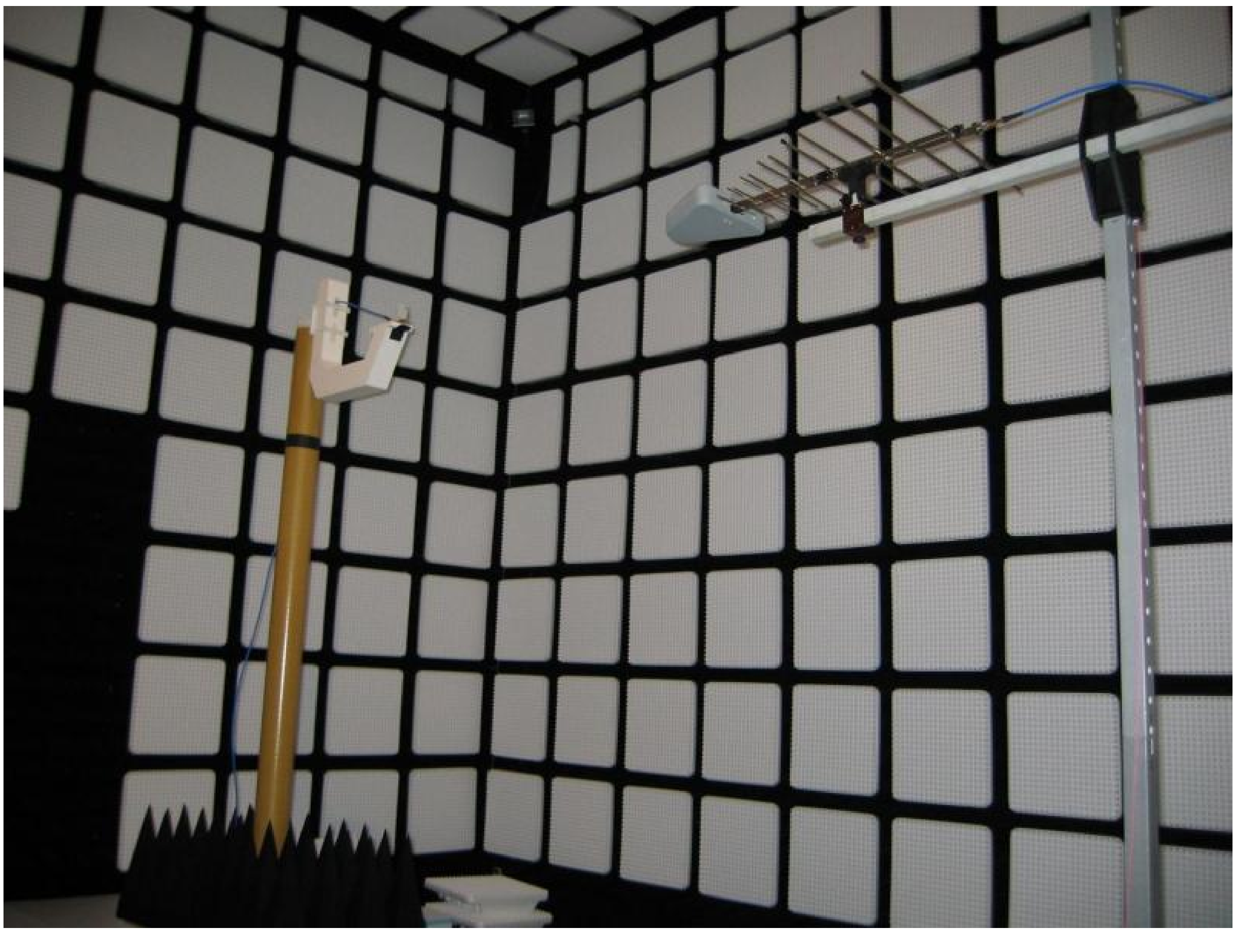


Anechoic chamber. Credit: University of Cambridge

A team of researchers from the University of Cambridge have unravelled one of the mysteries of electromagnetism, which could enable the design of antennas small enough to be integrated into an electronic chip. These ultra-small antennas - the so-called 'last frontier' of semiconductor design - would be a massive leap forward for wireless communications.

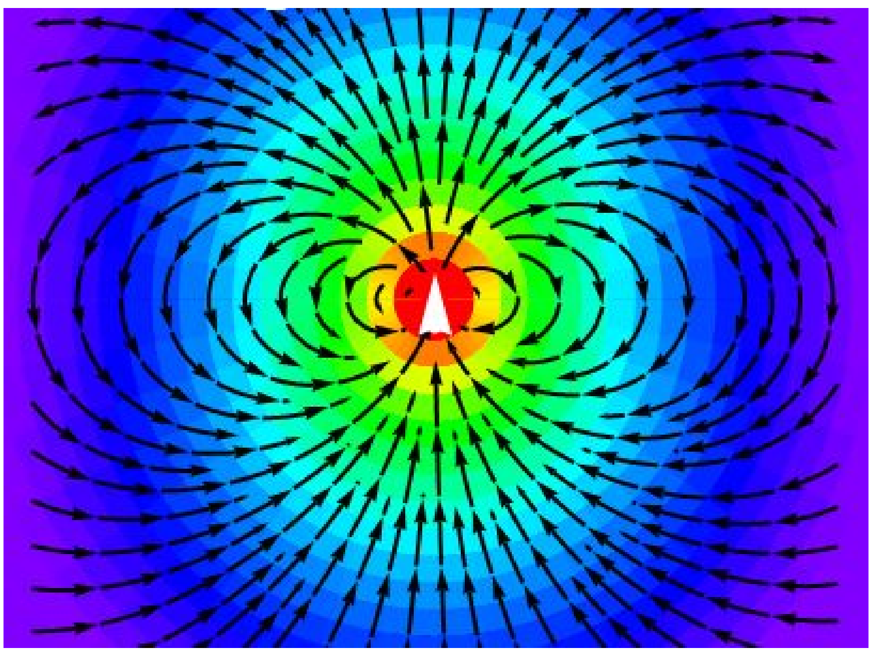
In new results published in the journal *Physical Review Letters*, the researchers have proposed that electromagnetic waves are generated not only from the acceleration of electrons, but also from a phenomenon known as symmetry breaking. In addition to the implications for wireless communications, the discovery could help identify the points where theories of classical electromagnetism and quantum mechanics overlap.

The phenomenon of radiation due to electron acceleration, first identified more than a century ago, has no counterpart in quantum mechanics, where electrons are assumed to jump from higher to lower energy states. These new observations of radiation resulting from broken symmetry of the electric field may provide some link between the two fields.

The purpose of any antenna, whether in a communications tower or a mobile phone, is to launch energy into free space in the form of electromagnetic or radio waves, and to collect energy from free space to feed into the device. One of the biggest problems in modern electronics, however, is that antennas are still quite big and incompatible with electronic circuits - which are ultra-small and getting smaller all the time.

"Antennas, or aerials, are one of the limiting factors when trying to make smaller and smaller systems, since below a certain size, the losses become too great," said Professor Gehan Amaratunga of Cambridge's Department of Engineering, who led the research. "An aerial's size is determined by the wavelength associated with the transmission frequency of the application, and in most cases it's a matter of finding a compromise between aerial size and the characteristics required for that application."

Another challenge with aerials is that certain physical variables associated with radiation of energy are not well understood. For example, there is still no well-defined mathematical model related to the operation of a practical aerial. Most of what we know about electromagnetic radiation comes from theories first proposed by James Clerk Maxwell in the 19th century, which state that electromagnetic radiation is generated by accelerating electrons.



Dipole radiation. Credit: University of Cambridge

However, this theory becomes problematic when dealing with radio wave emission from a dielectric solid, a material which normally acts as an insulator, meaning that electrons are not free to move around. Despite this, dielectric resonators are already used as antennas in mobile phones, for example.

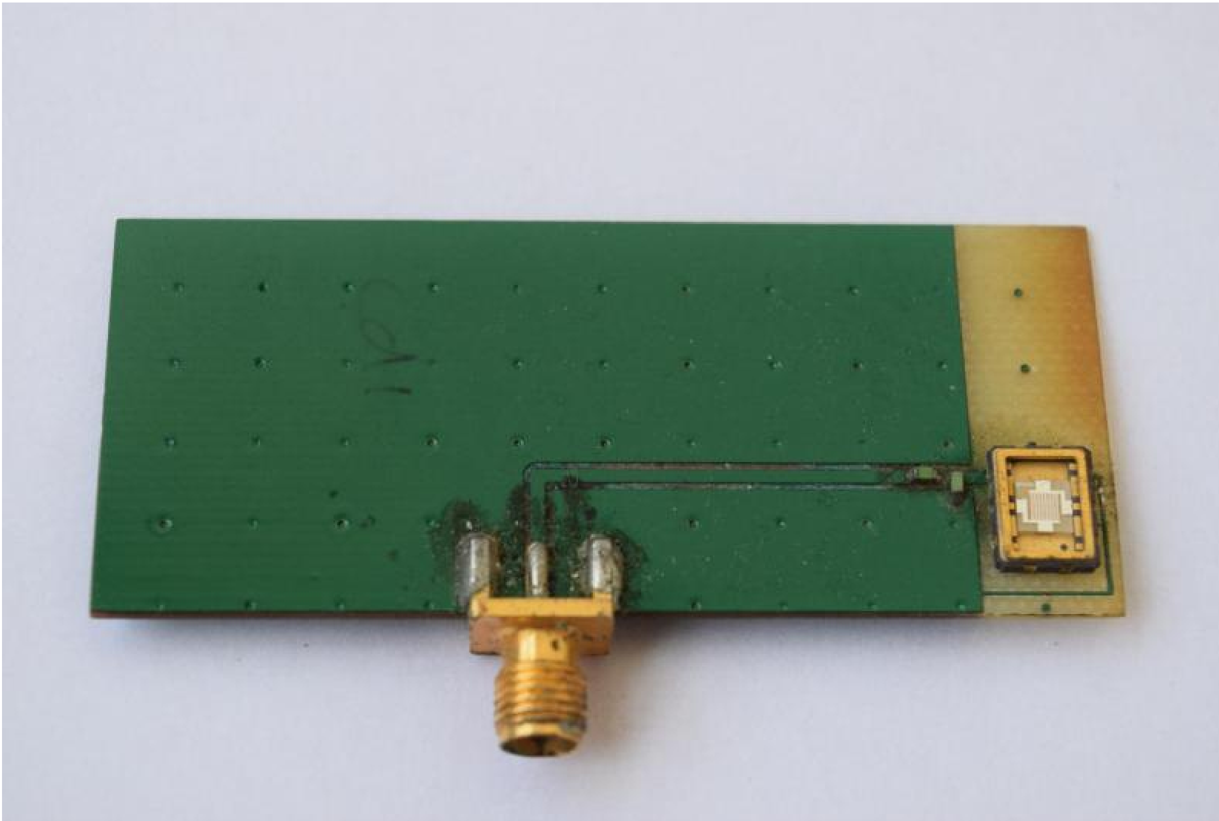
"In dielectric aerials, the medium has high permittivity, meaning that the velocity of the radio wave decreases as it enters the medium," said Dr Dhiraj Sinha, the paper's lead author. "What hasn't been known is how the dielectric medium results in emission of electromagnetic waves. This mystery has puzzled scientists and engineers for more than 60 years."

Working with researchers from the National Physical Laboratory and Cambridge-based dielectric antenna company Antenova Ltd, the Cambridge team used thin films of piezoelectric materials, a type of insulator which is deformed or vibrated when voltage is applied. They found that at a certain frequency, these materials become not only efficient resonators, but efficient radiators as well, meaning that they can be used as aerials.

The researchers determined that the reason for this phenomenon is due to symmetry breaking of the electric field associated with the electron acceleration. In physics, symmetry is an indication of a constant feature of a particular aspect in a given system. When electronic charges are not in motion, there is symmetry of the electric field.

Symmetry breaking can also apply in cases such as a pair of parallel wires in which electrons can be accelerated by applying an oscillating electric field. "In aerials, the symmetry of the electric field is broken 'explicitly' which leads to a pattern of electric field lines radiating out from a transmitter, such as a two wire system in which the parallel geometry is 'broken'," said Sinha.

The researchers found that by subjecting the piezoelectric thin films to an asymmetric excitation, the symmetry of the system is similarly broken, resulting in a corresponding symmetry breaking of the electric field, and the generation of electromagnetic radiation.



Microantenna. Credit: University of Cambridge

The electromagnetic radiation emitted from dielectric materials is due to accelerating electrons on the metallic electrodes attached to them, as Maxwell predicted, coupled with explicit symmetry breaking of the electric field.

"If you want to use these materials to transmit energy, you have to break the symmetry as well as have accelerating electrons - this is the missing piece of the puzzle of electromagnetic theory," said Amaratunga. "I'm not suggesting we've come up with some grand unified theory, but these results will aid understanding of how electromagnetism and quantum mechanics cross over and join up. It opens up a whole set of possibilities to explore."

The future applications for this discovery are important, not just for the mobile technology we use every day, but will also aid in the development and implementation of the Internet of Things: ubiquitous computing where almost everything in our homes and offices, from toasters to thermostats, is connected to the internet. For these applications, billions of devices are required, and the ability to fit an ultra-small aerial on an electronic chip would be a massive leap forward.

Piezoelectric materials can be made in thin film forms using materials such as lithium niobate, gallium nitride and gallium arsenide. Gallium arsenide-based amplifiers and filters are already available on the market and this new discovery opens up new ways of integrating antennas on a chip along with other components.

"It's actually a very simple thing, when you boil it down," said Sinha. "We've achieved a real application breakthrough, having gained an understanding of how these devices work."

More information: Electromagnetic Radiation Under Explicit Symmetry Breaking, *Physical Review Letters*, 2015. dx.doi.org/10.1103/PhysRevLett.114.147701

Provided by University of Cambridge

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