# A traveling-wave approach to high-field MRI

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# A traveling-wave approach to high-field MRI

By using magnetic fields to manipulate nuclear spins, magnetic resonance imaging excels at revealing subtle features in soft tissue. RF pulses excite the hydrogen nuclei in muscle, fat, or nerve fibers, say, that are aligned in a static magnetic field. When the RF frequency of the pulses matches the resonance, or Larmor, frequency, the spins tip and precess about the static field. Thanks to Faraday induction, the precessing magnetic moment then gives rise to an electromotive force that can be detected in a nearby coil of wire.

Typically, one coil transmits the RF pulses and another detects the induced signals, with both coils held close to the body to exploit the short-range coupling. That configuration has been used in clinical settings for decades, most often with imagers built using 1.5-tesla magnets.

But in recent years, medical imagers have been developed with magnetic fields exceeding 9 T. The signal-to-noise ratio scales roughly linearly with the field strength, and the boost in sensitivity can yield greater spatial resolution or higher scanning speeds. As the field increases, so does the resonance frequency required to excite hydrogen nuclei. At 7 T, it reaches 300 MHz, which corresponds to a wavelength of about 12 cm in tissue. That's on par with or smaller than RF coils that encircle the head or body. Because the wavelength is so small, the coils can produce standing-wave patterns in the tissue.

Such spatial inhomogeneities in the RF field are deleterious because the nonuniform excitations alter the image contrast, create blind spots at the nodes, and, in rare cases, even render field artifacts nearly indistinguishable from genuine pathologies. Researchers have made progress ironing out inhomogeneities by optimizing the superposition of several standing waves in a given region of interest using advanced coil designs and multichannel transmitters. But even then, the field patterns can be devilishly complex.

Fortunately, standing waves are not the only solution to Maxwell's equations. A variation in field amplitude can be compensated for by a spatial variation in phase, for example. On that basis, a group led by Klaas Pruessmann at ETH Zürich has now demonstrated an alternative approach that radically departs from the conventional view of MRI as a near-field, inductive technique. His team removed the RF coils entirely and used the cylindrical lining in an MRI cavity as a waveguide with a simple antenna placed at one end.[1] A patient inside the machine is thus exposed to a homogeneous traveling RF wave, and the same antenna that launches the wave can subsequently detect the spin signals. Indeed, the approach resembles ultrasound, which also probes and detects features in the far field, albeit it with acoustic waves.

The in vivo images of a human leg in the figure shown here demonstrate that traveling-wave MRI (left) can excite spins uniformly over a greater volume than can inductive MRI (right), at least in the high-frequency regime (300 MHz here). The new approach also confers another, perhaps unintended benefit: With the tight-fitting induction coils gone, patients may suffer less claustrophobia and system engineers may enjoy more design freedom.

Pruessmann acknowledges that the innovation was initially fortuitous. Only after his student David Brunner realized that what appeared as an image artifact was a genuine signal that originated well outside a local detector did the team explore the possibility that the signals could couple to modes of a waveguide. Moreover, the 7-T field strength and 58-cm bore width of Pruessmann's imager were not quite large enough together to sustain traveling waves. It took the presence of an additional dielectric like the human body—a bag of salt water, essentially—to push the cutoff frequency, at which waves stop evanescing and start traveling, below the Larmor frequency.

Not surprisingly, the body's presence can also complicate imaging. The large change in dielectric constant as waves travel from air to tissue produces reflections and diffractive effects inside the body. The researchers showed that by introducing some additional dielectric or absorber into the cavity with the proper electrical properties—a conductive water solution, for instance—it's possible to mitigate the impedance mismatch and the accompanying field inhomogeneities. Decades of optical and microwave engineering can now be mined for methods to exquisitely tune the imaging.

A more pervasive problem is noise. In Pruessmann's setup, the remote antenna exposes the entire body to RF waves. Conversely, the antenna is sensitive not only to signal from excited nuclei in some spatially selected region of the body but also to Johnson noise from random motion of ions throughout the body. The potential reduction in sensitivity might be outweighed in some cases by throughput speed and uniform coverage—screening a hundred laboratory mice at once, say. But Pruessmann envisions a hybrid approach for the highest signal-to-noise ratio needed in some human examinations. An antenna could excite the nuclei, but the job of local signal detection would again be relegated to an array of coils.

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## Reference

1. D. O. Brunner, N. De Zanche, J. Fröhlich, J. Paska, K. P. Pruessmann, *Nature* **457**, 994 (2009).