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Viewpoint

Electrical Signal Picks Up a Magnet’s Heartbeat

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Excitations in a magnet coupled to a microwave cavity can be detected electrically, providing a new
way to study magnets in the quantum regime.

Subject Areas: Magnetism, Spintronics

A Viewpoint on:
Spin Pumping in Electrodynamically Coupled Magnon-Photon Systems
Lihui Bai, M. Harder, Y.P. Chen, X. Fan, J. Q. Xiao, and C.-M. Hu
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A strong interaction between light and a magnet can produce a hybrid system with energy levels distinct from
either the light or the magnet on its own. In this “strong coupling” regime, quantum information can be easily
transferred from the light to the magnet and vice versa. This feature could be useful in quantum information tech-
nologies or as a way to use one component (say, the light) to probe the other. So far, most experiments have explored
strong coupling via its effects on the light. Can-Ming Hu at the University of Manitoba, Canada, and his
colleagues instead detect strong coupling directly from a magnet, which in their experiments is embedded in a mi-
crowave cavity [1]. The detection occurs via an electrical signal, suggesting their device could lead to new ways of
reading out the quantum state of a magnet with compact electronics.

Magnetism is a quantum phenomenon. But most mag-
nets can be described with classical physics because they consist of large numbers of spins. For example, the cou-
pling between a magnet and an electromagnetic wave can, in many cases, be completely described by Maxwell’s
equations. The quantum nature of a magnet can, how-
ever, be revealed if it is very strongly coupled to a light field, such as that in a cavity. The starting point is to pre-
pare the electromagnetic field in the cavity in a quantum state, such that the number of photons in the field is a
good quantum number. “Switching on” strong coupling between the cavity and the magnet involves aligning a
resonance frequency of the magnet with that of the cavity. Under these conditions, energy in the cavity—and
quantum information—can be transferred to the magnet. When the coupling is switched off, the quantum informa-
tion is “stored” in the magnet. Switching on strong coupling again transfers the state back into the microwave
cavity, where it can be read out with microwaves [2]. The key requirement of this protocol is that the transfer of en-
ergy be faster than the decay mechanisms in either the
microwave resonator or the magnet.

Hu and colleagues pursue this approach, but instead of reading out the state of the magnet indirectly with mi-
crowaves, they collect a direct electrical signal from the magnet. This signal is generated by the so-called spin
pumping effect, which occurs at the interface between a magnet and a metal [3]. The magnet in their experi-
ments is a thin rectangle of yttrium-iron-garnet, topped
with a 10-nanometer-thick layer of platinum. When the
magnet is excited by the cavity, it relaxes towards equi-
librium by transferring a spin-polarized current into the
adjacent metal layer. This spin current is accompanied
by a transverse charge current (a result of the inverse spin
Hall effect) and this spin pumping signal can be detected
with conventional electronics [4].

The researchers chose yttrium-iron-garnet because it
is an electrically insulating ferrimagnet with a magnetic
resonance frequency that lies in the gigahertz range and
is therefore excitable with microwaves. (The oscillating
magnetic field of the microwaves exerts a torque on the
ordered spins in the magnet, exciting their precession.)
The experiment consists of inserting the magnet struc-
ture into an aluminum microwave cavity and using an
external (static) magnetic field to tune the magnet’s res-
onant frequency to that of the cavity. As they do this
tuning, they measure the spectrum of microwaves from
the cavity and the spectrum of the electrical spin pump-
ing signal from the magnet (Fig. 1).

What they find is that both the electrical signal and
the cavity have sharp resonances when the magnet and
the cavity are uncoupled. But when the two components
are strongly coupled, these resonances broaden and split
in two, a phenomenon known as an “avoided level cross-
ing” that occurs when two systems with identical ener-
gies interact. Unlike the peaks in the microwave spec-
trum, however, the peaks in the electrical spectrum be-
come asymmetric in the strong-coupling regime. This

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FIG. 1: A hybrid system consisting of a magnet (indicated by its magnetization vector, the green arrow) strongly coupled to the microwave field (grey) in a cavity. The red lines indicate the magnet’s energy levels in a magnetic field, which are later modified when the magnet is strongly coupled to the cavity field. Hu and colleagues show they can read excitations in the strongly coupled magnet via an electrical signal (yellow). Their method could lead to new ways of reading the quantum information stored in a magnet with compact electronics. (APS/Joan Tycko)

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References


About the Authors

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Hans Huebl studied physics at the Technische Universität München, and he received his Ph.D. in 2007. In 2009, after a postdoc at the University in New South Wales, where he studied single donors for quantum information technologies, he moved to the Walther-Meißner-Institute for Low Temperature Research of the Bavarian Academy of Sciences and Humanities. His current research focuses on hybrid systems based on spins, nanomechanical elements, and superconducting circuits for enhanced solid-state spectroscopy.

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