Three teams find a way to measure frequencies with far better precision than previous techniques

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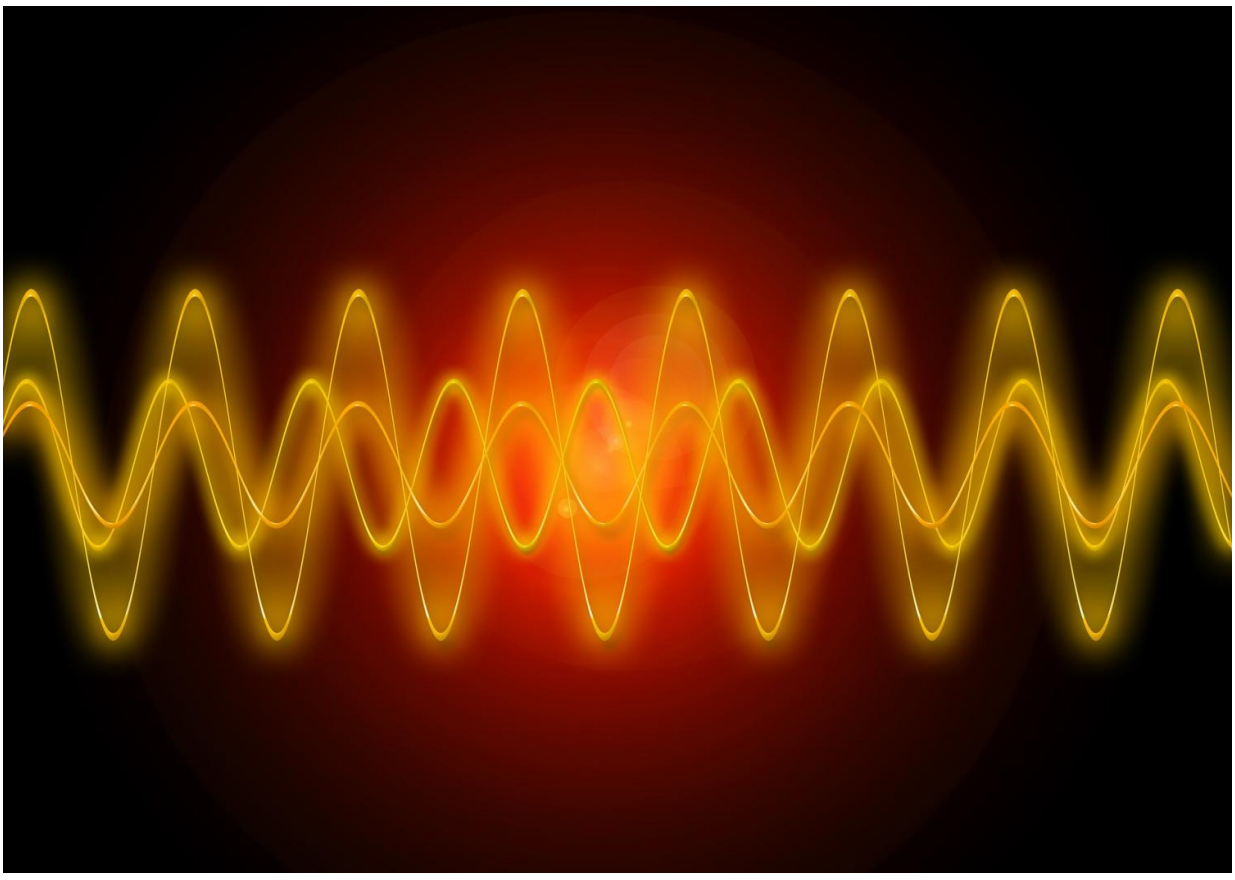

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(Phys.org)—Three teams working independently have found a nearly

identical way to boost the resolution of quantum magnetic sensors, allowing frequency measurements with far higher precision than previous techniques. Two teams, one with ETH Zurich, the other based at Ulm University in Germany, have published their results in the journal *Science*. The third team working at Harvard has yet to publish their results, though they have uploaded a copy of their paper to the *arXiv* preprint server. Andrew Jordan with the University of Rochester in the U.S. has published a Perspective piece in the same *Science* issue outlining the work by the teams and notes the "multiple independent discovery," which is interesting in and of itself.

Quantum sensing has become an essential tool for physicists—it measures frequencies in a wide variety of applications. But as has been noted, because it must interact with the environment, degradation occurs. In this new effort, all three teams found the same way to increase the accuracy of such sensing using a classical clock.

The improvement involved measuring a quantum qubit by studying defects in nitrogen vacancies (NVs) in a diamond—such vacancies have a magnetic spring, which makes them sensitive to a magnetic field. In this new effort, the researchers from the three teams isolated the NVs, allowing them to measure and manipulate them. They identified a means to enhance the response of the NV to a magnetic field, leading all three teams to improve their results by making repeated measurements at different time points while keeping track of how much time had passed—courtesy of an external clock to keep the measurements synchronized. This allowed for gathering more frequency information and hence improving accuracy. The researchers report improvements of nine orders of magnitude over previous methods.

The team in Germany took their work further by using their measurement technique to carry out NMR spectroscopy on a tiny sample of polybutene and discovered a problem—the molecules diffused past

the NV centers, preventing improved resolution. But as it turned out, the Harvard team came up with a solution to the same problem—getting the technique to work on groups of NV centers in the same diamond.

More information: J. M. Boss et al. Quantum sensing with arbitrary frequency resolution, *Science* (2017). DOI: 10.1126/science.aam7009

Abstract
Quantum sensing takes advantage of well-controlled quantum systems for performing measurements with high sensitivity and precision. We have implemented a concept for quantum sensing with arbitrary frequency resolution, independent of the qubit probe and limited only by the stability of an external synchronization clock. Our concept makes use of quantum lock-in detection to continuously probe a signal of interest. Using the electronic spin of a single nitrogen-vacancy center in diamond, we demonstrate detection of oscillating magnetic fields with a frequency resolution of 70 microhertz over a megahertz bandwidth. The continuous sampling further guarantees an enhanced sensitivity, reaching a signal-to-noise ratio in excess of 10^4 for a 170-nanotesla test signal measured during a 1-hour interval. Our technique has applications in magnetic resonance spectroscopy, quantum simulation, and sensitive signal detection.

Simon Schmitt et al. Submillihertz magnetic spectroscopy performed with a nanoscale quantum sensor, *Science* (2017). DOI: 10.1126/science.aam5532

Abstract
Precise timekeeping is critical to metrology, forming the basis by which standards of time, length, and fundamental constants are determined. Stable clocks are particularly valuable in spectroscopy because they define the ultimate frequency precision that can be reached. In quantum metrology, the qubit coherence time defines the clock stability, from

which the spectral linewidth and frequency precision are determined. We demonstrate a quantum sensing protocol in which the spectral precision goes beyond the sensor coherence time and is limited by the stability of a classical clock. Using this technique, we observed a precision in frequency estimation scaling in time T as $T^{-3/2}$ for classical oscillating fields. The narrow linewidth magnetometer based on single spins in diamond is used to sense nanoscale magnetic fields with an intrinsic frequency resolution of 607 microhertz, which is eight orders of magnitude narrower than the qubit coherence time.

High Resolution Magnetic Resonance Spectroscopy Using Solid-State Spins, arXiv:1705.08887 [quant-ph] arxiv.org/abs/1705.08887

Abstract
We demonstrate a synchronized readout (SR) technique for spectrally selective detection of oscillating magnetic fields with sub-millihertz resolution, using coherent manipulation of solid state spins. The SR technique is implemented in a sensitive magnetometer (~50 picotesla/Hz^(1/2)) based on nitrogen vacancy (NV) centers in diamond, and used to detect nuclear magnetic resonance (NMR) signals from liquid-state samples. We obtain NMR spectral resolution ~3 Hz, which is nearly two orders of magnitude narrower than previously demonstrated with NV based techniques, using a sample volume of ~1 picoliter. This is the first application of NV-detected NMR to sense Boltzmann-polarized nuclear spin magnetization, and the first to observe chemical shifts and J-couplings.