Atomic magnetometer improves "magnetic resonance without magnet"

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Nuclear magnetic resonance (NMR), a technique that is conventionally operated in large magnetic fields, is among common powerful analytical approaches applied in chemistry, biology and medicine. As a complementary tool to conventional high-field NMR, zero- and ultralow-field (ZULF) NMR offers improved spectral resolution and untruncated spin interactions. Specifically, as a complementary analysis tool to conventional high-field nuclear magnetic resonance, ZULF NMR detects nuclear magnetization signals in the submicrotesla regime. Combining with recently developed quantum-control techniques, ZULF NMR has shown to be promising in probing the frontiers of fundamental physics. Presently, ZULF NMR systems are normally equipped with high-quality magnetic shields to ensure that ambient magnetic-field noise does not dwarf the magnetization signal. An alternative approach would be to separate the magnetization signal from the noise based on their differing spatial profiles, as can be achieved using a magnetic gradiometer. Here, we present a gradiometric ZULF NMR spectrometer with a magnetic-field-gradient noise of 17 fT/cm $Hz^{1/2}$ in the frequency ranging from 100 to 400 Hz, based on a single vapor cell (0.7 × 0.7 × 1.0 cm^3). We show that the gradiometric spectrometer achieves 13-fold enhancement in the signal-to-noise ratio (SNR) compared to the single-channel configuration. By reducing the influence of the common-mode magnetic-field noise, this work enables the use of compact and low-cost magnetic shields. Gradiometric detection also proves to be beneficial for eliminating systematic errors in ZULF-NMR experiments searching for exotic spin-dependent interactions and molecular parity violation.

References

[1] M. Jiang et al. Experimental Benchmarking of Quantum Control in Zero-Field Nuclear Magnetic Resonance. Science Advances 4, eaar6327 (2018).

[2] M. Jiang et al. Magnetic Gradiometer for the Detection of Zero- to Ultralow-Field Nuclear Magnetic Resonance. Phys. Rev. Applied **11**, 024005 (2019).