Quantum-enhanced magnetic induction tomography

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Atomic magnetometry has seen significant attention in recent years, leading to various experimental approaches and applications. One prominent application of atomic magnetometers as sensors is the technique of magnetic induction tomography (MIT), a non-invasive imaging technique allowing to probe the conductive properties of a non-magnetic sample [1]. MIT exploits that an RF magnetic field induces eddy currents inside a conductive sample. These generate a response to the primary RF field, altering the total magnetic field as seen by the collective atomic spin ensemble. Monitoring the response of the collective spin continuously with a far-detuned laser allows for retrieving information about a magnetic field by monitoring the light polarization rotation using homodyne detection. Fundamentally, this measurement will be limited in sensitivity by the measurement's standard quantum limit (SQL).
To overcome the standard quantum limit governing an MIT measurement's attainable performance, quantum resources must be exploited to attain a quantum-enhanced version of the classical MIT. In our approach, we combine the well-known techniques of stroboscopic back-action evasion by probing the collective spin at twice the spins' Larmor precession with conditional spin-squeezing [2]. We exploit these for MIT to add quantum-enhanced magnetic induction tomography as a new quantum-enhanced sensing protocol. We can reduce the observed noise between unconditional and conditional measurements by 41 ± 1 % (Figure 1, blue and red error bars). Further, exploiting conditional spin-squeezing, we observe 11 ± 1 % lower noise than a back-action free measurement (green error bars). We verify the quantum enhancement by estimating the expected uncertainty for a continuous MIT compared to ours and find a noise reduction of 24 %.

References

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[3] Zheng, W., Wang, H., Schmieg, R., Oesterle, A., & Polzik, E. S. arXiv preprint: arXiv:2209.01920 (2022).

Figures

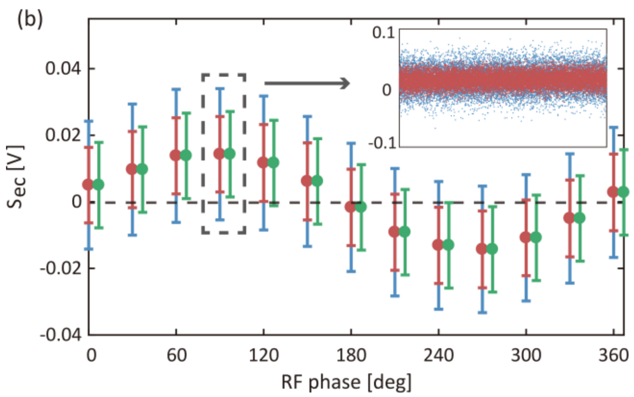

Figure 1: Recorded eddy current signals shown versus the relative RF phase. Red and blue error bars reflect conditional and unconditional measurements. Green error bars (shifted for clarity) reflect the expected noise for a back-action free measurement. Figure adapted from [3].