Towards resolving spatial structure of nanoscale environment using spin qubits subjected to dynamical decoupling

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Spin qubits are widely studied for application in nanoscale spectroscopy [1,2] of weak magnetic noise, especially chemical molecules localized near the surface of diamond nanocrystal containing an NV center. Such system can be described as a central electron spin interacting with nuclear spins. Controlled sequences of periodic qubit rotations dynamically decouple the qubit from low-frequency noise, while increasing its sensitivity to noise at characteristic frequencies associated with their periods. In the limit of weak coupling and relatively low magnetic fields (for NV center this corresponds to $B \leq 0.01$ T), dip of a qubit coherence as a function of duration of the sequence, gives information on the strength of hyperfine couplings [3,4]. On the other hand, in the limit of high magnetic fields ($B \geq 0.1$ T) we may also estimate what is the strength of interactions between the nuclear spins with respect to their coupling strength to a single or multiple qubits [5].

Recent work [6] showed theoretically how one can localize a classical magnetic moment using a two-qubit probe subjected to dynamical decoupling. However, we can explore more detailed structure of not necessarily classical signal coming from nuclear spins in proximity of the NV center. Especially, analysis of the intrabath couplings may help in resolving the spatial structure of dilute baths. The protocol seems even more promising when we consider addressing the NV center between $m_s = 0$ and $m_s = \pm 1$ or $m_s = -1$ and $m_s = +1$, as the former choice is a situation when conditional dynamics with respect to $m_s = 0$ corresponds to lack of hyperfine interactions, while not changing the intrabath dynamics.

We will present results on decoherence under Dynamical Decoupling (obtained using Cluster-Correlation Expansion method [7]) of one and two NV centers interacting with a small and dilute nuclear spin environment.

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[1] T. Staudacher, F. Shi, S. Pezzagna, J. Meijer, J. Du, C. a. Meriles, F. Reinhard, and J. Wrachtrup, Science **339**, 561 (2013).
[2] I. Lovchinsky, A. O. Sushkov, E. Urbach, N. P. de Leon, S. Choi, K. De Greve, R. Evans, R. Gertner, E. Bersin, C. Muller, L. McGuinness, F. Jelezko, R. L. Walsworth, H. Park, and M. D. Lukin, Science **351**, 836 (2016).
[3] W.-L. Ma, S.-S. Li, G.-Y. Cao, R.-B. Liu, Phys. Rev. Appl. **5**, 044016 (2016).
[4] P. Szańkowski, G. Ramon, J. Krzywda, D. Kwiatkowski, Ł. Cywiński, J. Phys. Condens. Matter **29**, 333001 (2017).
[5] F. Shi, X. Kong, P. Wang, F. Kong, N. Zhao, R.-B. Liu, J. Du, Nat. Phys. **10**, 21 (2013).
[6] J. Krzywda, Ł. Cywiński, P. Szańkowski, Phys. Rev. A, **96**, 042108 (2017).
[7] N. Zhao, S. Ho, R.-B. Liu, Phys. Rev. B, **85**, 1 (2012)