Many-body steady-state AC field quantum sensing

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Abstract. Quantum sensing is inevitably an elegant example for supremacy of quantum technologies over their classical counterparts. One of the desired endeavor of quantum metrology is AC field sensing. Here, by the means of analytical and numerical analysis, we show that many-body systems can be exploited efficiently for detecting the amplitude of an AC field. Due to the periodicity of the dynamics, any local block of the system saturates to a steady state which allows achieving precision for sensing the amplitude well beyond the classical limit. Remarkably, the scaling of precision with respect to the number of resources reaches close to the Heisenberg limit, along the line where Floquet gap vanishes. We associate the enhanced quantum precision to closing of the Floquet gap, resembling the features of quantum sensing in the ground state of critical systems. This shows the potential of many-body systems for providing quantum enhanced precision in AC field sensing.

Keywords: Quantum sensing, spin chain, Standard quantum limit, Heisenberg limit

Quantum systems have emerged as excellent sensors for detecting various types of fields [1], including weak magnetic electric and gravitational fields due to their extreme sensitivity against variation in the environment. The prospect of applica- tions for quantum sensing is very wide covering material science to biomedical analysis. In particular, AC field sensing has been the subject of intense theoretical and experimental research for the estimation of amplitude, frequency, and phase. The majority of these protocols, mainly implemented in nitrogen vacancy centers, utilize a series of spin-echo pulses to accumulate the information about the AC field in the phase of a coherent superposition of a single qubit, which is then converted into the amplitude at the readout stage. However, the ultimate precision is limited by the number of spin-echo pulses that one can apply within the coherence time.

In a fundamentally different route, one can exploit strongly correlated many-body quantum systems in and out of equilibrium for sensing[2]. In fact, thanks to the emergent of multipartite entanglement, many-body systems near criticality provide enhanced quantum precision. One may raise an important question whether strongly correlated many-body systems can also be beneficial for AC field sensing. If so, do they provide precision beyond the standard limit? The importance lies

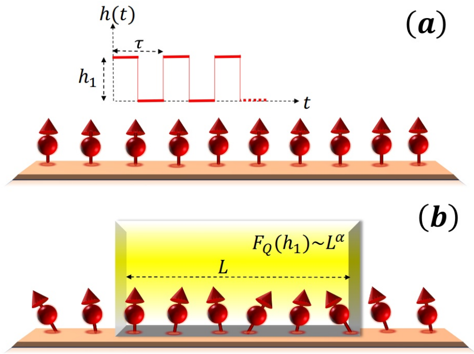

Figure 1 Sensing setup. (a) The many-body quantum quantum system of spin-1/2 particles, prepared in its ground state is interacting with a time-periodic magnetic field, h(t), of time period τ and strength h_1 . (b) In the steady state, a block of L contiguous spins are measured resulting a quantum Fisher information which scales with L as $F_Q(h_1) \sim L^{\alpha}$.

in the fact that, in this case, the AC field excites high energy eigenstates and thus the notion of ground criticality will no longer exists.

In this paper, we show that the many-body systems can indeed be very useful for estimating the amplitude of an AC field as the system is periodically evolve [3]. By employing the Floquet formalism, we analytically demonstrate that local degrees of freedoms relaxes to a steady state from which the information about the AC field can be extracted to a precision beyond the standard limit.

References

[1] C. L. Degen, F. Reinhard, and P. Cappellaro. Quantum sensing. Rev. Mod. Phys. 89, 035002 (2017).
[2] P. Zanardi, M. G. A Paris, and L. C. Venuti. Quantum criticality as a resource for quantum estimation. Phys. Rev. A 78, 042105 (2008).
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