Dynamics Beyond Hard-Core Bosons in Transmon Arrays

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Transmons can be considered as quantum mechanical multilevel systems being promising platforms for quantum information science. Taking the higher excited states into account, arrays of coupled transmons realize the attractive Bose-Hubbard model, see Fig. 1(a).
Here we present the higher exited states dynamics in the phase most relevant to transmon arrays [1] with the main focus on unitary [2] and nonunitary [3] effects. Our method combines high order perturbation theory and numerical simulations.
Since the interaction energy is approximately conserved, we observe various collective effects of many-body unitary dynamics. For example, a few bosonic excitations at one transmon group a single quasiparticle that experiences effective off-site interactions with other quasiparticles, individual bosons, and the edges of the arrays.
For nonunitary case, we distinguish three main processes: many-body decoherence, many-body dissipation, and transitions between the anharmonicity manifolds, see Fig. 1(b). The unitary dynamics is broken by these many-body processes. We describe in detail the numerical and analytical effects generated by dissipation and dephasing processes in transmons arrays dynamics. The dissipation induces transitions between the different boson-number manifolds that occur at a rate proportional to the instantaneous total boson number.
Dephasing reduces the coherence of many-body superpositions at a rate proportional to the squared distance between the many-body Fock states. Considering experimentally relevant parameters, including site-to-site disorder, we show that the state-of-the-art transmon arrays should be ready for the task of demonstrating coherent many-body dynamics using the higher excited states.

References

[1] O. Mansikkamäki, S. Laine, and M. Silveri, Phys. Rev. B, 103, L220202 (2021).
[2] O. Mansikkamäki, S. Laine, A. Piltonen and M. Silveri, PRX Quantum 3, 040314 (2022).
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Figures

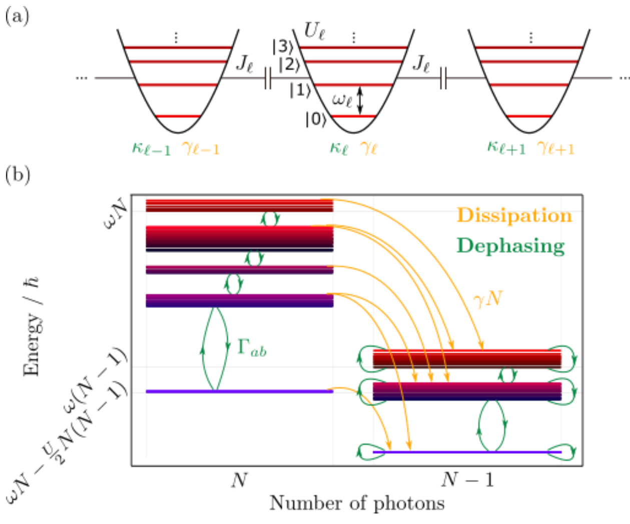

Figure 1: (a) A schematic of a 1D transmon array, where the transmons are represented as anharmonic oscillators. (b) A many-body energy level spectrum of a transmon array and a schematic showing many-body transitions due to the dissipation (yellow) and dephasing (green) processes. The coloured bands denote the anharmonicity manifolds containing several many-body eigenstates. The red and blue colours of the energy levels represent the relative contributions of the hopping energy and anharmonicity, respectively.