Analog simulation of four-level systems with parametrically tunable interaction strengths

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Flux-tunable transmon arrays are a promising platform for analog quantum simulation of the Bose-Hubbard (BH) model. However, their fixed anharmonicity — which maps to the BH interaction strength — typically confines simulations to the hard-core boson regime of at most one excitation per site. Parametric driving of the flux degree of freedom has recently been proposed as a means to tune the effective anharmonicity, though demonstrations have so far been restricted to the two-excitation manifold in one-dimensional chains. Here, we extend this approach to the three-excitation manifold and present a systematic phase analysis of the resulting effective Hamiltonians. This analysis lets us examine the lattice topology and observable selection under which the driven system faithfully realizes a BH model, extending analog simulation beyond the hard-core limit.