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Multi-mode ultra-strong coupling (II): divergence-free multi-mode quantum Rabi model for circuit QED MARIO F. GELY, Kavli Institute of NanoScience, Delft University of Technology,, ADRIAN PARRA-RODRGUEZ, Department of Physical Chemistry, University of the Basque Country UPV/EHU,, DANIEL BOTHNER, SAL J. BOSMAN, Kavli Institute of NanoScience, Delft University of Technology,, ENRIQUE SOLANO, Department of Physical Chemistry, University of the Basque Country UPV/EHU, IKERBASQUE, Basque Foundation for Science, GARY A. STEELE, Kavli Institute of NanoScience, Delft University of Technology, — In circuit QED, multi-mode extensions of the quantum Rabi model suffer from divergence problems. In circuits that provide no clear guidelines on how many modes play a role in the dynamics of the system, quantitative analysis is challenging due to these divergences. Here, we quantize a lumped element equivalent circuit of the vacuum-gap transmon archicture. As a consequence, the incremental addition of resonator modes renormalizes the qubit frequency and coupling strength, leading to a convergence of the spectrum, even for an infinite number of modes. The resulting multi-mode quantum Rabi Hamiltonian is expressed in terms of the bare qubit and resonator degrees of freedom, thereby retaining the analytical structure of the standard Rabi Hamiltonian. This approach allows us to gain insight into the quantum mechanics of inherently multi-mode circuit QED systems.

Sal J. Bosman
Kavli Institute of NanoScience, Delft University of Technology,

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