

A Josephson junction in a multimode environment: emergent quantum phase transition and exact low-energy duality

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The physics of a single Josephson junction coupled to a resistive environment is a long-standing fundamental problem at the center of an intense debate about the existence and properties of the superconducting-to-insulating Schmid-Bulgadaev transition. To circumvent the potential subtleties in the original derivation, we investigate the emergent criticality of a junction coupled to a multimode resonator when the number of modes is increased [1]. By solving the system via exact diagonalization, we show that at the transition point the spectrum displays universality (scale invariance) not only at low frequencies. This reflects in finite-frequency spectral signatures of the phase transition, in agreement with recent experiments. The spectrum at the critical point is successfully compared with analytical and numerical results obtained in the past [2]. Finally, we prove a low-energy exact self-duality of the model, that emerges from two different finite-size circuits with different conserved quantities [3]. This confirms and generalizes the approximate self duality that is usually invoked, and proves the independence of the transition point on the ratio of Josephson to charging energy.

References

- [1] Giacomelli L., Ciuti C., Nature Communications, 15(1), 5455 (2024)
- [2] Paris, Giacomelli, Daviet, Ciuti, Dupuis, Mora, Phys. Rev. B, 111(6), 064509 (2025)
- [3] Giacomelli L., Devoret M. H., Ciuti C., arXiv preprint arXiv:2504.14651 (2025)

Figures

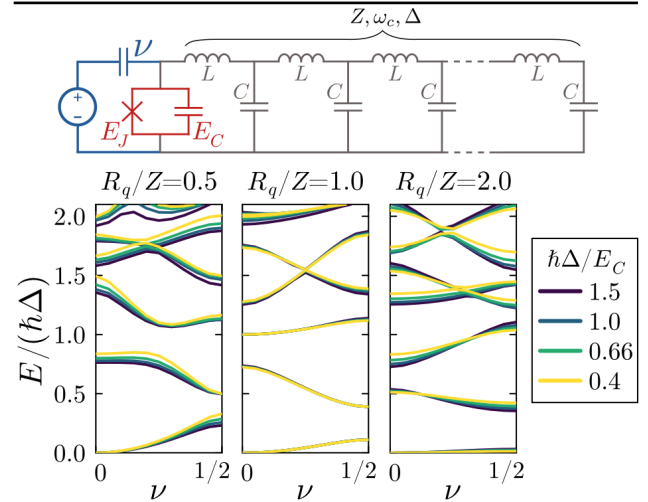


Figure 1: Top: the considered system. Bottom: band spectra for different environment impedances Z and different system sizes (Δ). At the critical point the spectrum is scale-invariant.

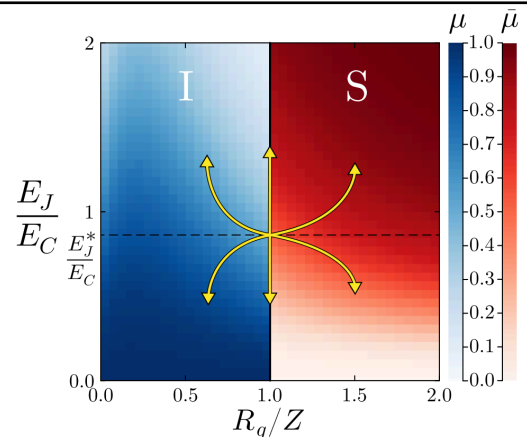


Figure 2: Phase diagram. Points with the same color intensity show low-energy spectral duality, as indicated by the arrows.