

Controlled Parity of Cooper Pair Tunnelling in a Hybrid Superconducting Qubit [1]

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Abstract

Superconducting quantum circuits derive their nonlinearity from the Josephson energy-phase relation. Besides the fundamental $\cos(\phi)$ term, this relation can also contain higher Fourier harmonics $\cos(k\phi)$ corresponding to correlated tunnelling of k Cooper pairs. The parity of the dominant tunnelling process, i.e. whether an odd or even number of Cooper pairs tunnel, results in qualitatively different properties, and controlling this opens up a wide range of applications in superconducting technology. However, access to even-dominated regimes has remained challenging and has so far relied on complex multi-junction[2] or all-hybrid architectures[3].

Here, we demonstrate a simple "harmonic parity qubit"; an element that combines two aluminum-oxide tunnel junctions[4] in parallel to a gate-tunable InAs/Al nanowire junction[4] forming a SQUID, and use spectroscopy versus flux to reconstruct its energy-phase relation at 85 gate voltage points. At half flux quantum, the odd harmonics of the Josephson potential can be suppressed by up to two orders of magnitude relative to the even harmonics, producing a double-well potential dominated by even harmonics with minima near $+\pi/2$.

The ability to control harmonic parity enables supercurrent carried by pairs of Cooper pairs and provides a new building block for Fourier engineering in superconducting circuits.

References

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- [2] M.Bell et al., Phys.Rev.Lett. 112, 167001 (2014)
- [3] T..Larsen et al., Phys. Rev. Lett. 125, 056801 (2020)
- [4] A.Bozkurt et al., SciPost 15, 204 (2023)
- [5] D.F.Bofill et al, Phys. Rev. Applied 24, 044099 (2025)

Figures

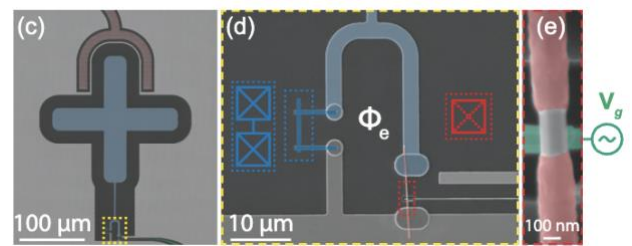


Figure 1: Harmonic Parity Qubit realized in this work. The Josephson element is a SQUID with two SIS junctions in series on the left branch and a S-Sm-S junction on the right. The harmonic content of the two SQUID branches interfere as a function of the magnetic flux threading the loop. At half flux quantum, the gate voltage controls whether an even or odd number of Cooper pairs dominates the tunneling process.

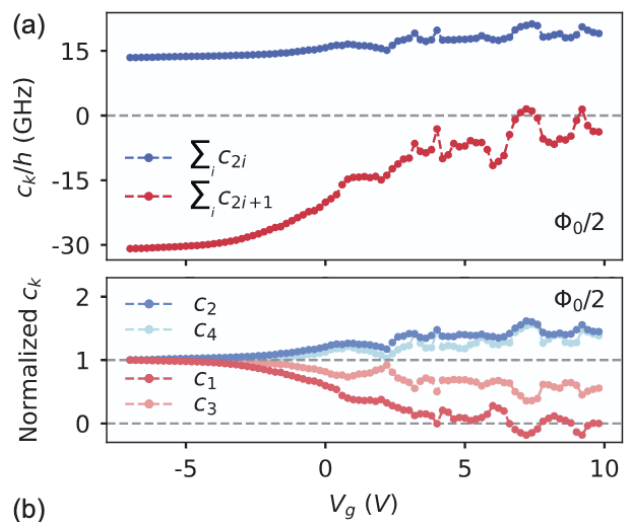


Figure 2: Harmonic content versus gate voltage. The potential is decomposed into harmonics via a Fourier series $U(\phi) = \sum c_k \cos(k\phi)$. The odd harmonics are progressively suppressed with increasing V_g and change sign, while even harmonics remain large and vary slowly.