

Superconducting Quantum Interference in Nanowire Networks for Digital and Quantum Logic

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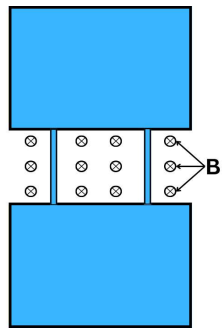
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INTRODUCTION

- Superconducting quantum interference **underpins** many classical and quantum technologies
- Superconducting nanowires provide a route to scale these devices down by **~1000x**
- **Question:** Nanowires + quantum interference → new logic and qubit architectures?
- **Approach:** Study N parallel nanowires with corrected current phase relationship

DEVICE

Fig. 1. Example 2 superconducting nanowire device with applied magnetic field



THEORY

Quantum Interference Effects

$$\phi_i = \phi_j + 2\pi b(x_i - x_j) - 2\pi v_{i,j} \quad (1)$$

b : normalized magnetic field
 $v_{i,j}$: # of vortices between i -th & j -th nanowire

Corrected Nanowire Current-Phase relationship:

$$\frac{I(\phi)}{I_0} = \frac{\phi}{\phi_0} - a \left(\frac{\phi}{\phi_0} \right)^{2m+1} \quad (2)$$

ϕ = phase difference across nanowire
 ϕ_0, I_0, a, m = constants (m is an integer)

METASTABILITY

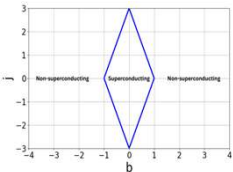


Fig. 2. Example Vorticity Stability Region (VSR)

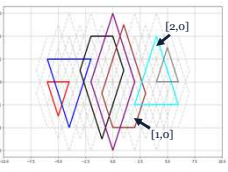


Fig. 3. Different vorticity arrays produce different VSRs

TOWARDS DIGITAL LOGIC [1,2]

Device's Global Symmetry \cong Charge-Parity-Time (CPT) Symmetry

Or: The device's symmetry is mathematically equivalent to CPT symmetry

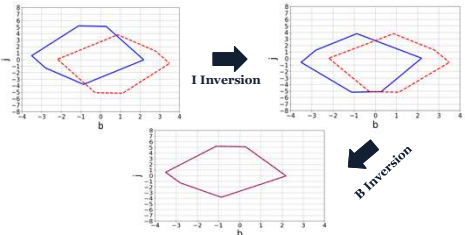


Fig. 4. IBV Symmetry ↔ Device's Global Symmetry

Parity Symmetric Device → Magnetic Symmetric VSR



Fig. 5. Parity (P) Transformation

Parity-Time Symmetric Device → Current Symmetric VSR

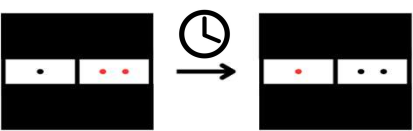


Fig. 6. Time (T) Inversion

Breaking Time & Parity Symmetry → Superconducting Diode Effect

- This means...
- 1.) Vortices must be present
 - 2.) Vorticity array is not parity-symmetric

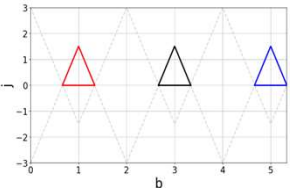


Fig. 7. Perfect Superconducting Diode

TOWARDS QUANTUM LOGIC [3]

QHO + Anharmonicity → Qubit

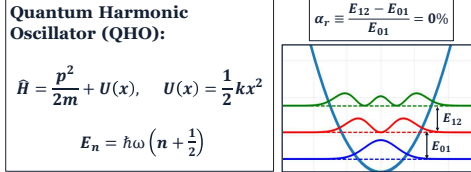


Fig. 8. QHO produces evenly-spaced energies

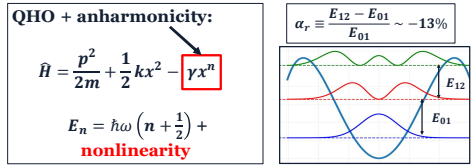


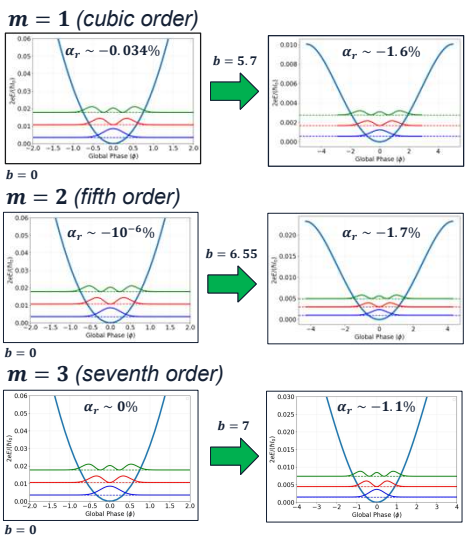
Fig. 9. Anharmonic QHO produces unevenly-spaced energies

Nanowires with very Linear CPRs + Magnetic Field → Good Qubit

Mapping Anharmonic QHO to a 2-nanowire device...

$$\hat{H} = -4E_c \frac{\partial^2}{\partial \phi^2} + A(b)\phi^2 - B(b)\phi^{2(m+1)} \quad (3)$$

Increasing b : $A(b) \downarrow$ $B(b) \uparrow$ (non-linear increase w/b)



KEY TAKEAWAYS

1. **Generalized** quantum interference effects between N parallel nanowires
2. Global device symmetry is **isomorphic** to the Charge-Parity-Time symmetry
3. Parity symmetry \Leftrightarrow Magnetic symmetry
4. Parity-Time symmetry \Leftrightarrow Current symmetry
5. Breaking parity and time symmetries produces a **perfect** superconducting diode
6. Added **power law correction** to nanowire CPR from calculated Usadel Equations
7. Adding magnetic field to 2 nanowires **increases anharmonicity**

FUTURE WORK

On-going experimental work to verify theoretical predictions

REFERENCES

- [1] Sun C., Bezryadin A. (2025) Multiple Nanowire Superconducting Quantum Interference Devices: Critical Currents, Symmetries, and Vorticity Stability Regions, Nano Express
- [2] Sun C., Zhao Z., Bezryadin A. (2025) Perfect Superconducting Diode and Supercurrent Range Controller, Physics Letters A
- [3] Sun C., Bezryadin A. (2026) A Dayem Loop Qubit Based on Interfering Superconducting Nanowires (under review)

ACKNOWLEDGEMENTS

