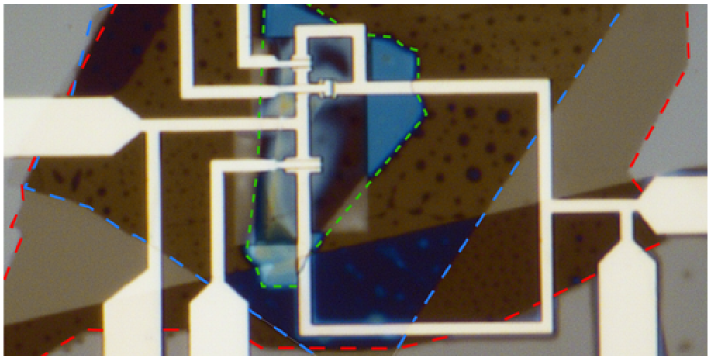
A New Nonlinearity for Superconducting Circuits

Researchers have isolated a high-order term in the behavior of a Josephson junction, which could lead to longer-lived superconducting qubits.

By **Marric Stephens**

Qubits based on superconducting circuits come in various forms, but one thing they have in common is their reliance on Josephson junctions, which give a circuit the nonlinearity necessary to generate qubit states. Simon Messelot from CNRS Grenoble, France, and his colleagues have now built a superconducting circuit whose nonlinear response differs from that of conventional Josephson-junction-based circuits [**1**]. The circuit design could lead to superconducting qubits with much longer coherence times.

A conventional Josephson junction is a short constriction or insulating section within a superconducting circuit. Current flows across the junction by quantum tunneling, and the magnitude of this current is related to the phase difference φ between the wave functions of the superconductor on either side of the junction. In traditional junctions, the current-phase relation (CPR) is nonlinear based on a $\sin(\varphi)$ dependence. But in recent years, researchers have developed junctions based on semiconductors and two-dimensional materials whose CPR can include higher-order terms such as $\sin(2\varphi)$. Nevertheless, the behavior is typically dominated by the lowest order $\sin(\varphi)$ term.



Credit: S. Messelot *et al.* [**1**]

Messelot and colleagues fabricated a superconducting circuit incorporating three graphene-based Josephson junctions. These junctions were arranged to form two superconducting quantum interference devices (SQUIDs), which are circuits in which the junctions' φ values are sensitive to magnetic fields. By applying a magnetic field and controlling the voltage across every junction, the team suppressed the $\sin(\varphi)$ term in one of the SQUIDs, causing its CPR to be dominated by $\sin(2\varphi)$.

A superconducting circuit governed by $\sin(2\varphi)$ has a more complex energy landscape, with two energy minima. A qubit whose states are defined by these minima would be longer lived and easier to manipulate than a conventional superconducting qubit.

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REFERENCES

1. S. Messelot *et al.*, "Direct measurement of a $\sin(2\varphi)$ current phase relation in a graphene superconducting quantum interference device," **Phys. Rev. Lett. 133, 106001 (2024).**