Emulating weak localization using a solid-state quantum circuit

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• Phase Qubits
• Device and Idea
• Basic pulse sequences
• Emulation of WL
• Results
• Conclusion
Phase Qubit I

- Current biased Josephson junction (SNS)
  \[ I(t) = I_0 \sin \left( \frac{2\pi \Phi}{\Phi_0} \right) \]
  \[ \frac{d\delta}{dt} = \frac{2eV}{\hbar} \]
- Biasing JJ close to \( I_0 \)
- Tilted washboard potential, tilt given by \( \frac{\delta}{I_0} \)
- Energy levels in the well with non degenerate energy spacings
- First two levels can be used as qubit states
- Built-in read out:
  - State \( |1> \rightarrow \text{voltage drop of } 2\Delta/e \)
  - State \( |0> \rightarrow V=0 \)

Phase Qubit II

- 2 level system
- $T_1$ relaxation time
- $T_2$ decoherence time of two eigenstates

Resonator and phase qubit:

- Capacitive coupling
- Used to shuttle qubits back and forth
- Coupling described by Jaynes-Cummings Hamiltonian

$$H = \sum_{i=0}^{N} \hbar g (a^+ \sigma^-_i + a^{} \sigma^+_i)$$

iSWAP: bring Re in resonance with Q

$$|e\rangle \otimes |0\rangle \leftrightarrow |g\rangle \otimes |1\rangle$$
Device and idea

- 3 Qubit system and 1 resonator (Re)
- Create an entangled state between Re and Q3 and Q2
  \[ |\Psi\rangle = \frac{1}{\sqrt{2}} (|eg0\rangle + |ge0\rangle) \]
- Manipulate the state in a random way (=random walk in meso. system) and read out
Pulse sequence I – coherent transfer

1. Put Q1 in $|e>$
2. Bring Re and Q1 in resonance ➔ transfer of photon and immediately detune Q1
3. Tune Q2 and Q3 in resonance with Re for $\tau$ and then detune them again
4. Repeat 2
5. Readout each qubit

- Resonator allows coupling of the three qubits via photons
- Distribute photon between the control qubits Q2 and Q3 and the readout qubit Q1
Pulse sequence II – phase coherence

Create entangled state between Q2, Q3 and Re:

\[ |\Psi\rangle = \frac{1}{\sqrt{2}} (|eg0\rangle + |ge0\rangle) \]

1. Photon is equally distributed to the control qubits
2. Apply static detuning to each qubit
3. Swap to Re and readout only Q1

- Decoherence due to by 1/f flux noise
- Hahn-Echo refocuses the phase via \( \pi \)-pulse

→ Tunability of the phase coherence
Pulse sequence III

- Perform 100 different control sequences
  - Variation of $\delta_r$ and $\tau_r$
- Average qubit outcomes yields $P_{\text{return}}$
  - Find Q1 in $|e> \rightarrow$ constructive interference (=increased resistance)
• Simulation and Experiment are in good agreement
• WL characteristic very well visible; increase of amplitude with $T_\phi$
• Oscillations away from $\delta=0 \rightarrow$ UCF
• However amplitude very large for WL
• Tune disorder via total measurement time $\tau_{\text{total}}$
• $\tau_{\text{total}}$ randomly generated via Gaussian distribution
• Observe a slight increase in localization with increasing disorder at $\delta=0$
• Peak also becomes wider
• No metal-to-insulator transition observed
• Add phase shift
• detuning pulse at the end of control pulse
  → induce a relative $\pi$ phase rotation between the splitted photon
  → reversal of symmetry of detuning pulses
Conclusion

Qubit/Quantum circuits:
- High level of control of a superconducting qubit
- Platform for emulation of quantum mechanically driven effects

Experimental:
- Universal conductance fluctuations (UCF) can be seen
- Is it possible to emulate a proper WAL signal like this?