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Using parametric programming to create controllable delay lines for quantum computing

Stanford scientists have developed a parametrically programmable delay line that uses superconducting circuits to store and manipulate quantum information with dynamic control capabilities. This virtual delay line can arbitrarily delay, translate, or swap quantum pulses while adding less than one photon of noise, enabling more compact and versatile quantum computing hardware. The technology enables the ddevelopment of hardware-efficient quantum computers by providing the compact, high-quality delay lines required for well-established protocols that significantly reduce quantum computing hardware overhead.

Building practical quantum computers requires compact delay lines that can store and manipulate quantum information, but current solutions force companies to choose between physical size and functionality. Traditional delay lines would require impractical dimensions while existing compact approaches like slow-light metamaterials and acoustic waveguides offer only fixed, static operation once built. This limitation forces quantum computing companies to compromise on the dynamic control capabilities needed for advanced quantum algorithms. The lack of programmable delay lines represents a significant barrier to developing the hardware-efficient quantum computers that well-established protocols require.

Stanford's parametrically programmable delay line overcomes these limitations by using superconducting circuits to create a virtual delay line with unprecedented dynamic control capabilities. The system uses parametric drives to couple storage resonators with a readout resonator, enabling real-time manipulation of quantum pulses through simple adjustments to drive frequencies, amplitudes, and phases. This approach allows operators to selectively choose which photon echoes to emit, translate pulses in time, and even swap two pulses - all while adding less than one photon of noise to preserve quantum information integrity. Importantly, the technology has been successfully demonstrated in laboratory conditions and can be readily manufactured using existing industrial superconducting qubit foundries, making it immediately scalable for commercial quantum computing applications.

Stage of Development:
Prototype
Continued research - improve the delay line by optimizing the fabrication processes and combining the delay line with superconducting qubits

Applications

- Development of hardware-efficient quantum computers with reduced overhead
- Implementation of compact delay lines for superconducting quantum circuits
- Dynamic control and manipulation of quantum information in real-time
- Enhancement of quantum computing protocols requiring programmable pulse control

Advantages

- Provides dynamic, real-time control over quantum pulses through parametric programming
- Compact virtual implementation eliminates need for impractically long physical waveguides
- Adds less than one photon of noise, preserving quantum information integrity
- Compatible with existing industrial superconducting qubit foundries for scalable manufacturing
- Enables unprecedented capabilities including pulse translation, selective echo emission, and pulse swapping

Publications

- • Makihara, T., Lee, N., Guo, Y., Guan, W., & Safavi-Naeini, A. (2024). A parametrically programmable delay line for microwave photons. Nature Communications, 15(1), 4640.

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