Assembling Control Architecture for Integrated Quantum Circuits

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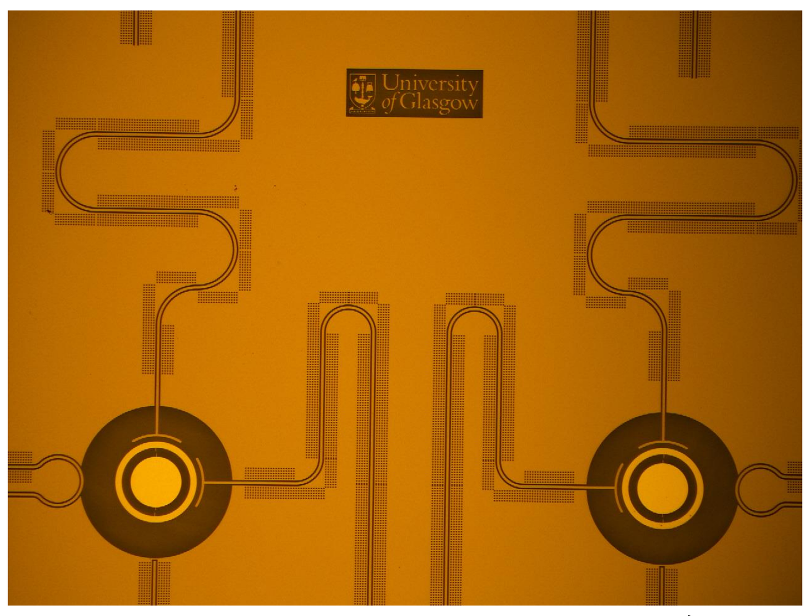
Abstract

Quantum computers use the probabilistic nature of quantum systems and its resulting phenomena, such as superposition and entanglement states, to perform some computations which are essentially impossible for classical systems to reproduce. The fundamental block of these devices are two level systems called qubits (quantum bits) which encode the quantum information that is manipulated during these computations. Achieving a regime where these devices can perform calculations that no other classical computer can do in a reasonable time is something that has recently been accomplished [1], but that comes with huge engineering challenges, specifically increasing the number of qubits in a single chip and manipulating all of them simultaneously.

This project aims to study new ways of controlling qubit and quantum chips using scalable technology, namely with superconductor electronics based on Single Flux Quantum (SFQ) pulses. The control architectures developed using this technology can also be implemented in quantum technologies, such as single photon detectors or SQUID-based magnetic sensing.

Quantum Circuits & Cryogenic Setups

Quantum Circuits like qubits and single photon detectors need to be cooled down to extremely low temperature of the order of milliKelvin (mK). After the circuits are fabricated, they are mounted on a Dilution Refrigerator (DR) cryostat and measured using conventional room temperature electronics. By using superconductor electronics, most of these bulky and expensive electronics can be replaced by a single chip placed near the quantum circuit [2].



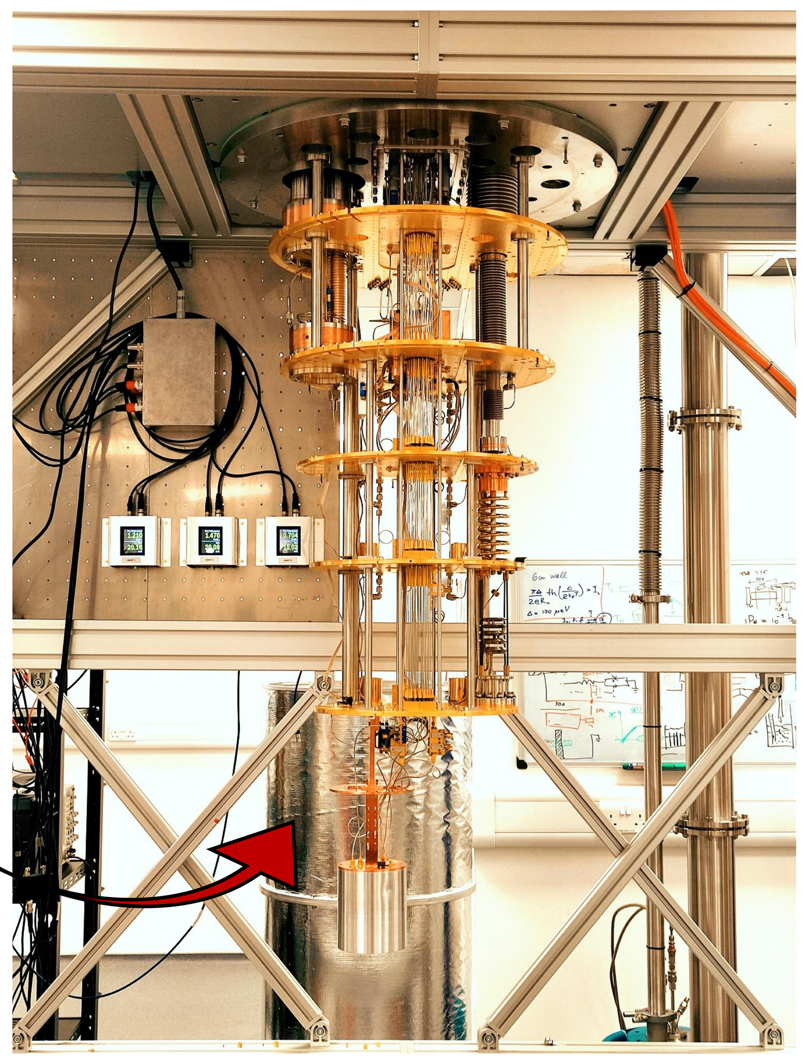


Fig. 1 – [Left] Two-Qubit quantum circuit designed and fabricated at the University of Glasgow. [Right] Dilution Refrigerator cryostat

Key Results & Future Work

- → Implemented standard cryogenic setup to measure quantum circuits at mK temperatures (qubits, …) and successfully measured test samples. Studied noise photon flux and filtering effects on same setup [4]
- → Designed and simulated programmable SFQ-based circuits to generate digital multi-tone signals
- → Designed and simulated Josephson Pulse Generator device and physical layout of the chip for fabrication
- → Tested SFQ chips cryogenically

Having designed the two main circuits of the project, the next step is to finish the physical layout and start fabrication of such devices. Afterwards, measurements are to be done and compared to traditional quantum chip control systems.

Superconductor Electronics

Based on Josephson Junctions, superconductor electronics are capable of extremely low energy consumption and high frequency operation [3] which makes it the perfect choice for integration with other quantum circuits based on superconductors.

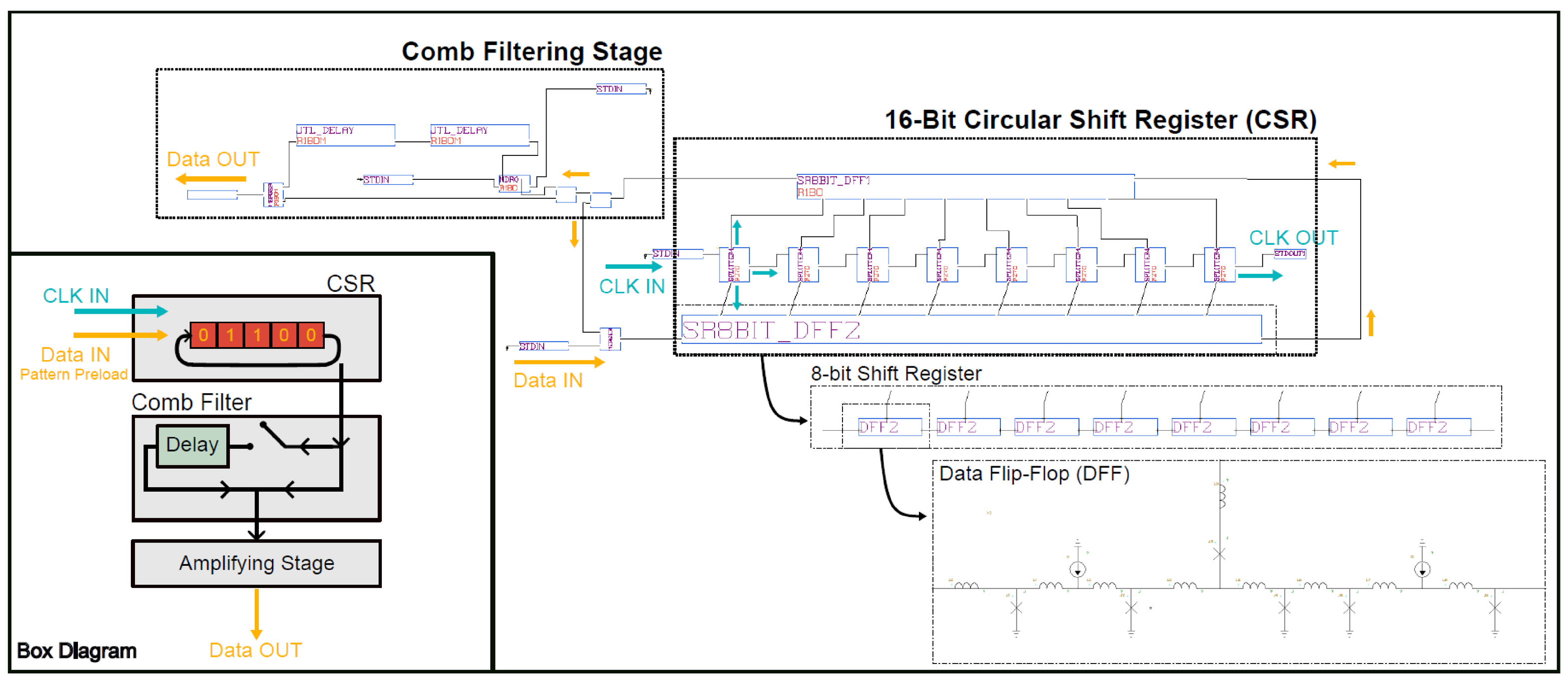


Fig. 2 – RSFQ based Multi-Tone Signal Generator for frequency multiplexing control of arrays of quantum circuits.

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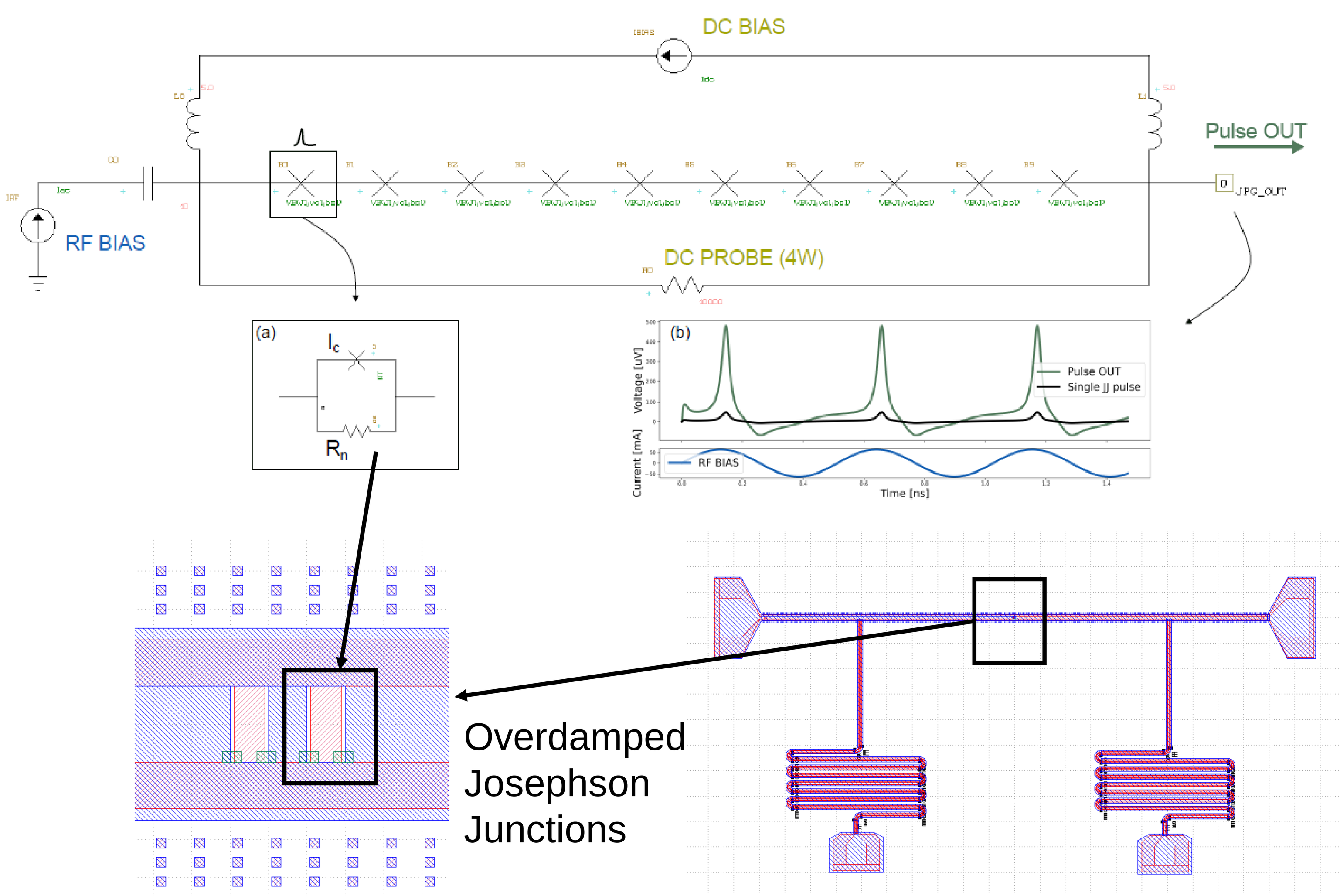

Fig. 3 – Josephson Pulse Generator for Qubit Pulsed Control. A series array of Josephson Junctions biased by an RF and DC current can generate quantized pulses which excite the qubit state.
[Top] Design and Schematic. [Bottom] Physical Layout for fabrication.

References

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[3] *Energy-Efficient Single Flux Quantum Technology*, O. Mukhanov 2011
[4] *Engineering the microwave to infrared noise photon flux for superconducting quantum systems*, S. Danilin, J.Barbosa et al 2022

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