



QRC-4-ESP

QUANTUM RESERVOIR COMPUTING
FOR EFFICIENT SIGNAL PROCESSING

Project Deliverable

D2.1 Fabricated, optimised and tested 5-qubit QR

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1. Introduction

1.1 Scope of the Deliverable

This deliverable outlines the development, fabrication, and experimental testing of a 5-qubit Quantum Reservoir Computing (QRC) prototype for efficient signal processing. It provides a detailed account of the project's objectives, emphasizing the design of the prototype, its experimental setup, and the initial results obtained during testing. The primary aim is to assess the performance and dynamic behaviour of the QRC system, addressing aspects like resonance transmission, single-tone spectroscopy, and bistability to refine the design and guide further research.

1.2 Structure of the Deliverable

This deliverable is organized into several sections, beginning with an introduction that defines the scope and structure. It then delves into the fabrication process of the QRC sample, detailing the physical and technical specifications. The subsequent section explains the experimental setup, including the equipment and configurations used for testing. The results are discussed in a dedicated section, segmented by specific experiments like transmission analysis, single-tone spectroscopy, and bistability observations. The deliverable concludes with a summary of findings and recommendations for future improvements in design and testing.

2. Sample

We designed, fabricated and characterised a five-qubit QRC prototype which consisting of a half-wavelength coplanar transmission line resonator coupled to flux dependent transmon qubits, spaced 600 μm apart. The optical image of the bonded sample is shown in Fig.1. Each qubit has its own individual DC lines (for DC flux bias) and RF lines (for microwave input power), see Fig. 2. The chip was fabricated of aluminium by making use of shadow evaporation technology. The transmission line resonator was designed to have an inductive coupling to the external measurement setup. The total resonator's length is 8400 μm . To match to 50 Ohm, the line width was chosen to be 10 μm and the gaps width to be 5 μm . The total chip size is 10 x 10 mm^2 .

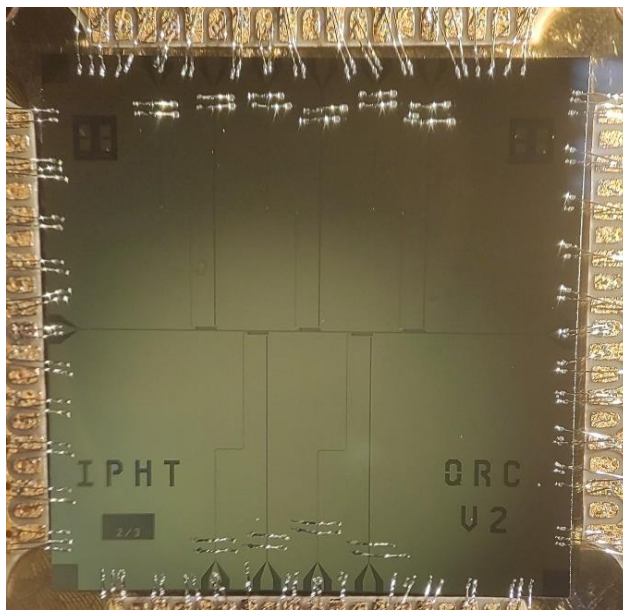


Figure 1 – Photo of the sample installed in a holder

For the first proof of principle of QRC we used only DC bias lines, to test how multiple transmon qubits behave together in such a circuit configuration.

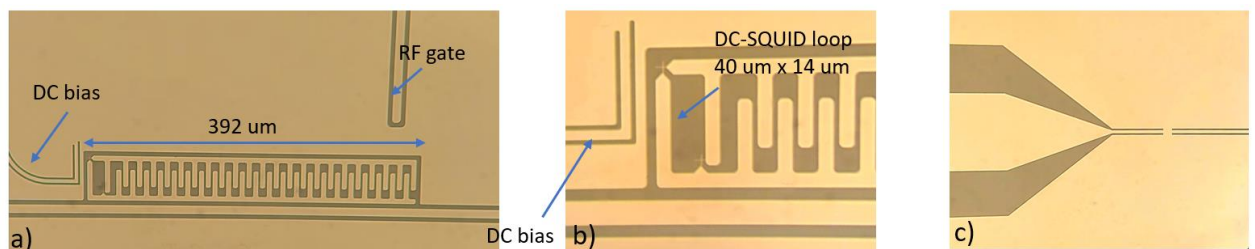


Figure 2 – Optical microscope images: a) single transmon qubit with individual DC bias and RF gate lines; b) zoomed area of the single transmon qubit DC-SQUID loop, c) inductive coupling: width 30 μm

3. Setup

The experiments were carried out in a dilution refrigerator with a base temperature of about 10 mK. Fig.3 shows a diagram of the experimental setup. The total attenuation in the input measurement line was -70 dB (including attenuation in cables, not shown in Fig.3). An output signal was amplified using a HEMT cryogenic amplifier. The HEMT amplifier is isolated from the sample by a double isolator with a 4-8 GHz bandwidth and 40 dB isolation. Individual DC bias lines for the corresponding qubit were implemented via twisted pairs, which were filtered at the 4 K stage by a low pass filter (cut off frequency is 30 kHz). The flux bias of each qubit was controlled by a low-noise current source.

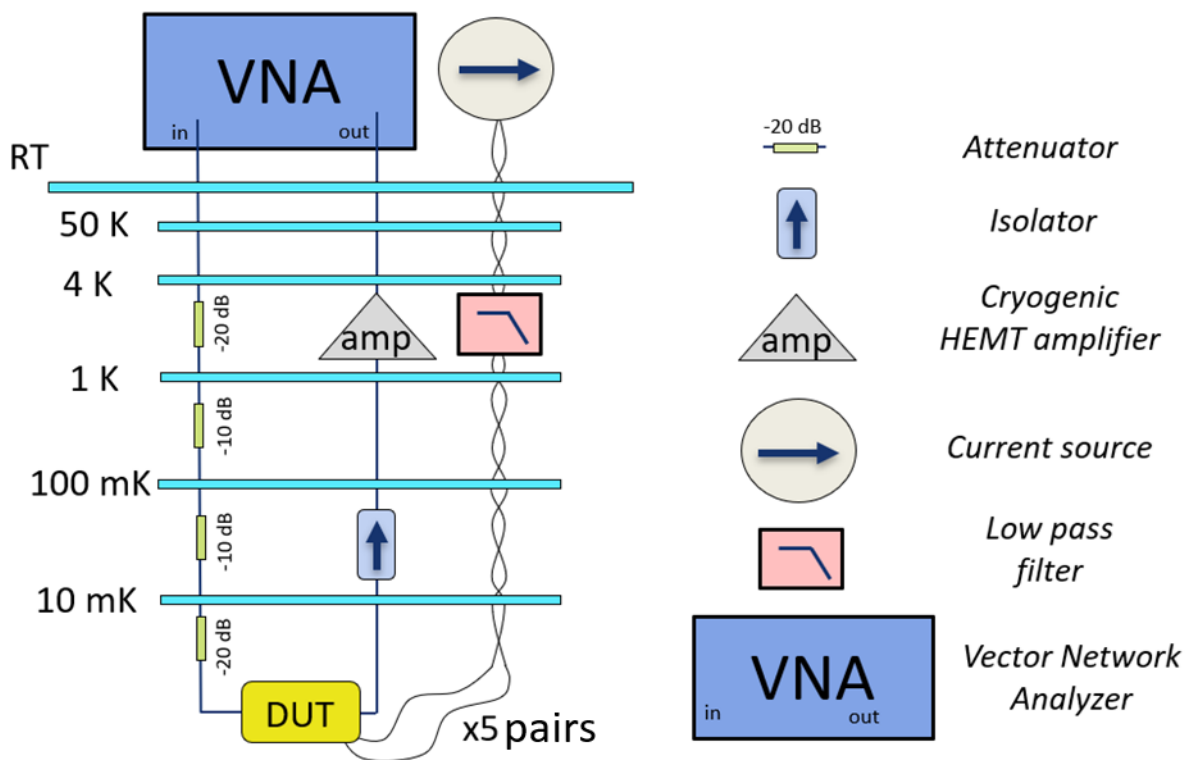


Figure 3 – Measurement setup

The sample was mounted in a specially designed and manufactured sample-holder at the lowest temperature stage. To suppress external microwave and magnetic noises, two gold-plated copper shields and two additional permalloy shields were used.

4. Results and discussion

In this section, we present the obtained experimental results and highlight further research.

4.1 Transmission

The transmission coefficients for different input powers are plotted in Fig.4. Here qubits were not tuned by external flux bias. The shape of the resonance curves requires extra study, due to the unconventional inductive coupling of the resonator to the input (output) transmission lines

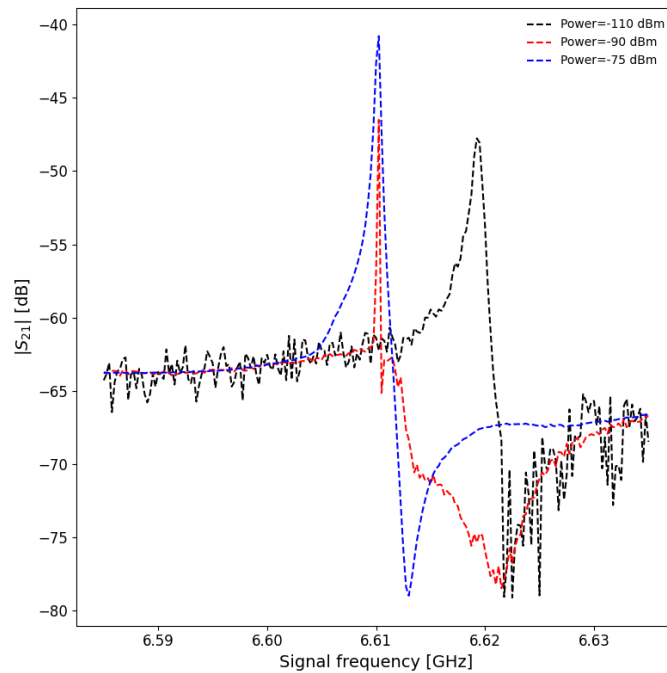


Figure 4 – Resonance curve at different input powers

4.2 Single tone spectroscopy

Next, we measured how transmission coefficient depends on the external flux bias applied to the different qubits. In Fig.5 we present a photograph of the sample with the corresponding DC bias channels mapping to visualized the flux bias application. Having determined corresponding current channels, the results of these experiments are shown in Fig.6. The technical problem was occurred for DC4, where applied current could not exceed 1 mA without causing a mixing chamber heating, so that these results are not demonstrated.

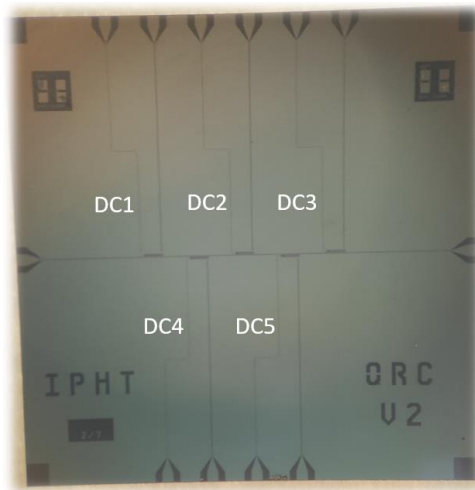


Figure 5 – Mapping of DC bias channels

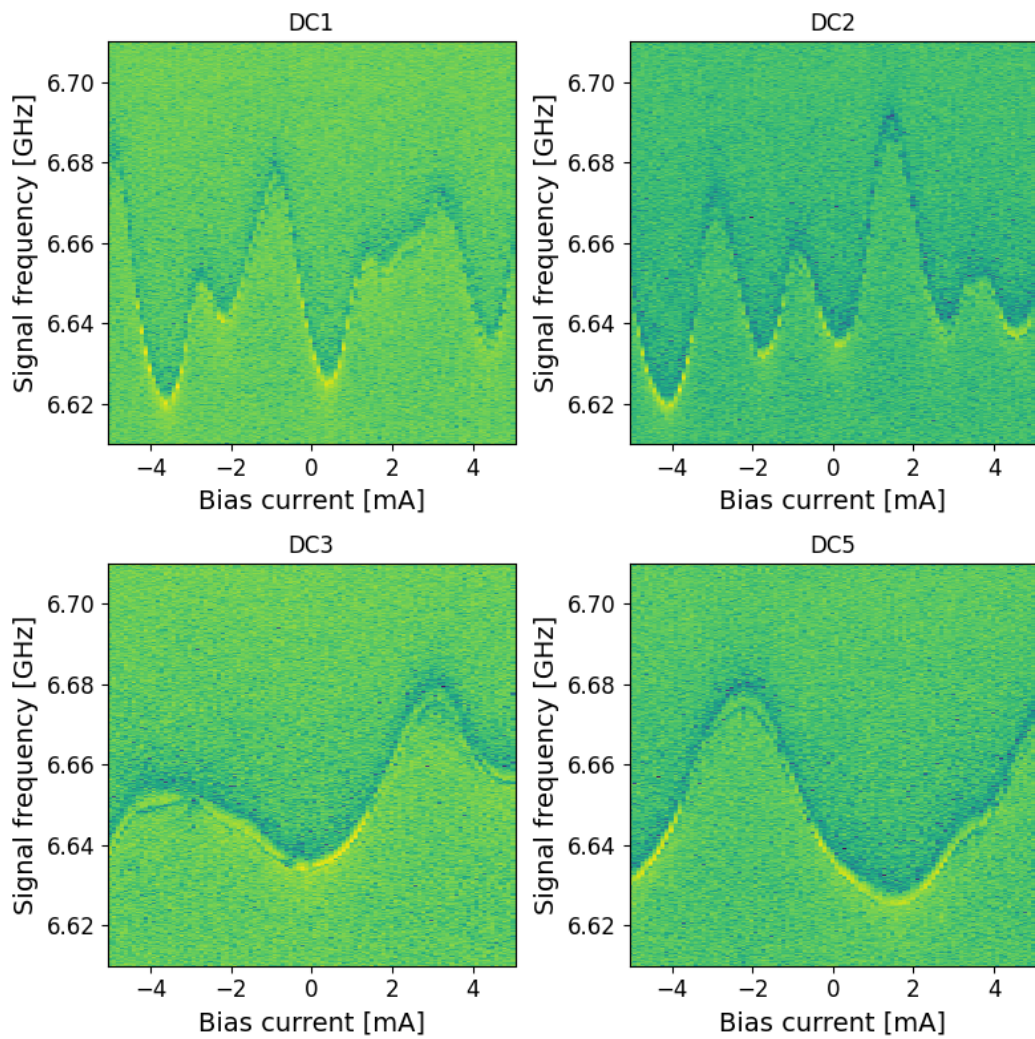


Figure 6 – Single tone spectroscopy for four DC bias channels

4.3 Bistability

Unexpectedly, we observed that under some conditions the transmission demonstrates bistable behavior. The example of measure bistable behavior is shown at Figure 7, where time-dependence of the transmission coefficient at single frequency was measured. The measured data allow to calculate number of points, that we detect in one of these two stable states, by setting a threshold value shown as red line at Figure 7a. That brings us to the simple check, that the observed behavior is related to the qubits-resonator interaction dynamics. We count number of such points as a function of bias applied to the channel DC1, which is shown at Figure 7b. Thus, first guess is that this dynamic depends on the detuning between qubits' transition frequencies and the resonator. Anyway, this interesting feature requires further study

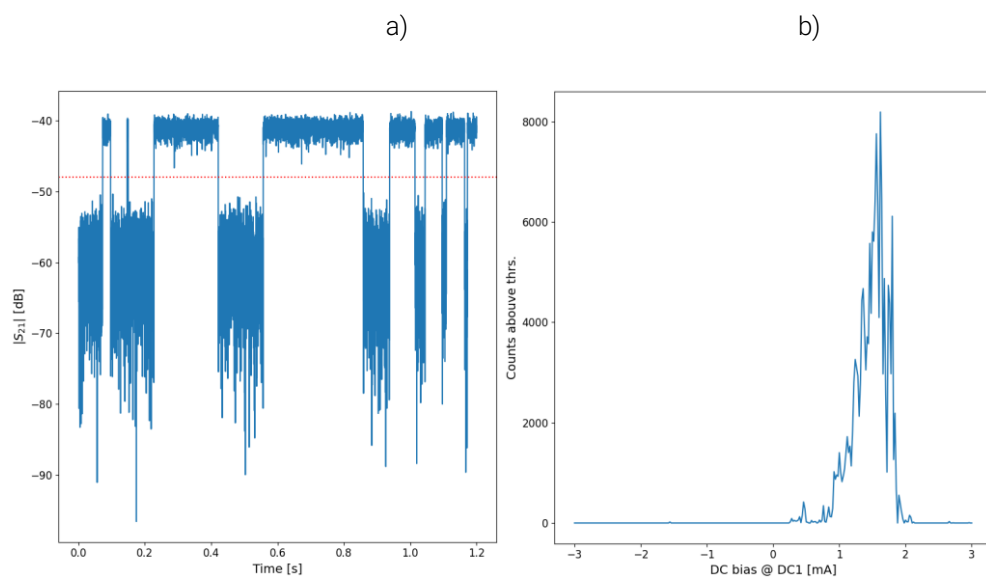


Figure 7 –Observed bistable behavior. a) Time dependence of transmission coefficient S21. b) counts of the state above the threshold as a function of applied bias current.

5. Conclusion

Summarizing, we have measured the transmission of the five qubits QRC prototype in details, demonstrating promising system dynamics. However a deeper understanding of transmission line resonances, single-tone spectrums shapes as well as bistability requires further measurements as well as additional design and setup improvements.