Highly Connected Qubit Network Using Multimodal Circuits as Building Blocks

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Abstract. Superior inter-qubit connectivity and higher dimensional gates enable efficient implementation of quantum algorithms in quantum processors. Most superconducting quantum processors typically have nearest neighbour connectivity and use native two-gates only. Multimodal circuits like the trimon, offer an alternative implementation of multi-qubit blocks with high fidelity native multi-qubit gates. Here, we experimentally demonstrate a multi-qubit gate between a multimodal system and a conventional transmon qubit and explain how it can be scaled to make a highly connected network of multi-modal systems.

Keywords: Superconducting Qubits, Quantum Processor, Multi-qubit Gate

Superconducting circuits are one of the most promising candidates in the race for building a quantum computer with the demonstration of several intermediate scale quantum processors[1,2] and recent achievement of quantum supremacy on a programmable 53 qubit processor[3]. Since most superconducting processors implement only nearest neighbour coupling, one needs to apply several additional gates to perform an operation between qubits which are not directly connected. Such limited connectivity often limits the performance of most quantum algorithms and quantum simulations [4,5].

We recently introduced multimodal circuits[6,7] which implement all-to-all connected qubit networks with native multi-qubit gates. The N normal modes of such circuits give rise to N qubits. Strong always on coupling allows one to implement fast N-qubit gates as well. We recently demonstrated a three-qubit processor[8] using a three-mode circuit nicknamed the trimon which highlights the advantages of native three-qubit gates and higher connectivity. Based on that, we propose an alternative strategy (see Fig.1) for scaling up quantum processors, using multi-modal circuits as building blocks for superior connectivity among qubits.

In this work[9] we demonstrate a simple multi-qubit system, containing only one transmon[10] and a two-qubit multi-modal circuit, called dimon. We couple the two with a 3D waveguide bus cavity, mediating an exchange interaction between one of the modes of the dimon and the transmon.

We use this interaction and implement the multi-qubit operation by driving the transmon at the transition frequency of the coupled dimon mode. This turns on a cross resonance interaction[11,] that approximately implements a conditional ZX operation in the circuit.

We first experimentally study the effect of cross resonance drive on the system as a function of the detuning between the two qubits and identify the optimum range of detuning for the system. In the next experiment, we use the optimum detuning and carefully calibrate the cross-resonance interaction to implement a ZX gate with a fidelity exceeding 97%, measured by randomized benchmarking[12]. The fidelity is limited due qubit decoherence (limiting the fidelity to 97.9%) and a small cross-kerr (ZZ) interaction[13] between the dimon and the transmon. This result paves the way towards building quantum processors with multi-modal circuit as building blocks.

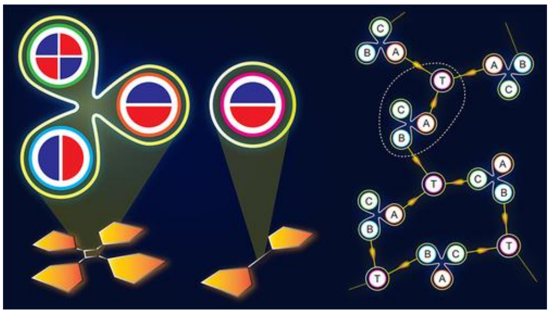

Fig.1. Multimodal circuits as building blocks for quntum processors. One of the dipolar modes is coupled with the transmon. An extension of the design for a highly connected intermediate scale quantum processor.

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