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Deep Cryogenic Temperature CMOS Circuit and System Design for Quantum Computing Applications

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Abstract

Quantum computing is a fascinating and rapidly evolving field of technology that promises to revolutionize many areas of science, engineering, and society. The fundamental unit of quantum computing is the quantum bit that can exist in two or more states concurrently, as opposed to a classical bit that can only be either 0 or 1. Any subatomic element, including atoms, electrons, and photons, can be used to implement qubits. The chosen sub-atomic elements should have quantum mechanical properties. Most commonly, photons have been used to implement qubits. Qubits can be manipulated and read by applying external fields or pulses, such as lasers, magnets, or microwaves. Quantum computers are currently suffering from various complications such as size, operating temperature, coherence problems, entanglement, etc. The realization of quantum computing, a novel paradigm that uses quantum mechanical phenomena to do computations that are not possible with classical computers, is made possible, most crucially, by the need for a quantum processor and a quantum SOC. As a result, Cryo-CMOS technology can make it possible to integrate a Quantum system on a chip. Cryo-CMOS devices are electronic circuits that operate at cryogenic temperatures, usually below 77 K (−196 °C).

Keywords: cryo-CMOS, quantum SOC, quantum processor, scalability, IC design, performance analysis

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1. Introduction

In order to solve several computing issues related to medication discovery, cybersecurity, climate predicting, etc., quantum computers can offer exponential speedup. At present, quantum computers run with just 50 qubits. In this range itself, quantum computer surpasses supercomputers in specific applications. However, functional, practical applications would require millions of qubits. The connection concerns solid-state qubits operating at 20 milli Kelvin within dilution refrigerators and control electronics. The control electronics modules are located outside the dilution refrigerator. The controller's location outside is one of the main challenges to scaling from 50 qubits to millions of qubits. Long coaxial cables connect these electronics. A 50-qubit processor requires hundreds of connections, digital to analogue converters, mixers, and amplifiers. The system's scalability issue became more acute in this situation. Most of the IC manufacturing industries and companies give their attention towards realizing quantum computing using CMOS technology. Since our world relies on classical computing, quantum computing is based on quantum mechanics. Thus, various quantum researchers try to control quantum bits utilizing CMOS technology. If that is possible, the size and operating temperature of the quantum computer can be scale down for practical applications. The solution to the problem as mentioned above is using cryogenic integrated circuit design across devices, circuits and systems.

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