Design of a Generalized Quantum Arithmetic Logic Unit (QALU) Using QFT and Multiplexed Unitaries

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Abstract

This paper proposes a modular and generalized **Quantum Arithmetic Logic Unit (QALU)** that can perform essential arithmetic and logical operations using:

- Quantum Fourier Transform (QFT)
- Standard quantum gates (CNOT, Toffoli)
- A quantum multiplexer for unitary selection

The architecture supports **QFT-based addition and subtraction**, **quantum XOR and AND**, and **dynamic operation switching** via **multiplexed unitaries**. Its reprogrammable and modular structure makes it a suitable candidate for the arithmetic core in scalable **Quantum Processing Units (QPUs)**.

Highlights

- General-purpose quantum ALU framework
- Arithmetic: QFT Adder and Subtractor
- Logic: Quantum XOR (CNOT), AND (Toffoli)
- Operation Selection via Quantum Multiplexed Unitaries (QMU)
- Modular design with extensible unitary blocks

Operations Table

Index	Unitary	Operation
00	U_1	QFT Adder
01	U_2	Quantum XOR
10	U_3	Quantum AND
11	U_4	QFT Subtract

Core Concepts

1. QFT-Based Arithmetic

Adder:

$$R|\psi\rangle = \sum e^{2\pi i(x+a)y/N}|y\rangle$$

$$\text{IQFT}(R|\psi\rangle) = \sum |x+a\rangle$$

Subtractor:

$$R|\psi\rangle = \sum e^{2\pi i(x-a)y/N}|y\rangle$$

$$\text{IQFT}(R|\psi\rangle) = \sum |x-a\rangle$$

2. Logical Operators

Quantum XOR (CNOT):

$$\text{CNOT}|\psi\rangle = |x \oplus a\rangle$$

Quantum AND (Toffoli):

$$\text{Toffoli}|\psi\rangle = |x \cdot a\rangle$$

3. Quantum Multiplexed Unitaries (QMU)

Dynamic selection of operations using:

$$m = \sum |z\rangle\langle z| \otimes U_z$$

Each index of the control register corresponds to a specific operation unitary.

Contents

- `Generalized_Quantum_Arithmetic_Logic_Unit.pdf`: Full research paper describing the QALU architecture

Citation

If you use or reference this work in your research, please cite it as:

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