

Advantages and drawbacks in photonic quantum computing

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1 Introduction

The initial method proposed for creating qubits in a photonic quantum computer is path encoding, introduced by [1]. In this approach, the positions of the photons—referred to as spatial modes—define the state of the qubit. Spatial modes can, for example, correspond to optical fibers. In this chapter, we adopt the term "mode" to specifically refer to spatial modes for the sake of clarity and simplicity in notation. The state of the system is represented by $|n_0, n_1, \dots, n_{m-1}\rangle_{01\dots(m-1)}$ where $0, 1, \dots, (m-1)$ denote the spatial modes occupied by n_0, n_1, \dots, n_{m-1} photons, respectively, thereby representing a Fock state. The concept of polarization enables the design of novel quantum photonic circuits that do not require the inclusion of CNOT gates. To emphasize the significance of polarization, we present a comparative study between the non-polarized formulation of Grover's algorithm and its polarized counterpart. However, polarization does not inherently provide an advantage in photonic circuits, as the readout process necessitates specialized operations that rely on additional spatial modes essential for extracting the results.

2 Basic concept in photonic

2.1. Fock state definition

The definition of a qubit relies on a single photon distributed over two spatial modes: $|0\rangle = |1,0\rangle_{01}$, $|1\rangle = |0,1\rangle_{01}$. The Fock states $|n\rangle_j$ represent mode j in which n photon may be found. We are considering here a specific case where a single photon is distributed over two modes. When the photon occupies mode 0, the system corresponds to the Fock state $|1,0\rangle_{01}$, which is sometimes written simply as $|1,0\rangle$; however, this simplified notation should be avoided to prevent confusion between qubit states and Fock states. For example, the Fock state $|1,0\rangle_{01}$ is denoted as $|0\rangle$. A very specific list of gate that are applied to Fock state are defined in photonic circuit including but not limited to Beam Splitter, $PS(\alpha)$, $PERM_{i,j}$. It is possible to define the classical qubit gate using the photonic gate and to have a correspondence. **Table 1** gives some elements of these gate to components correspondence.

Table 1: Correspondence between classical gates and their realization using optical components

Qubit operator	Photonic circuit	Qubit operator	Photonic circuit
$X = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$		$Z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$	
$Swap_{12} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$		$Y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$	
$H = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$		$CX_{ij} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$	

2.2. Grover implementation

Disregarding graphical conventions, the circuit can be drawn to explicitly introduced the operators, resulting in the circuit shown in Figure 1.

The equivalence between conventional qubit encoding and encoding using Fock states is presented in Table 1.

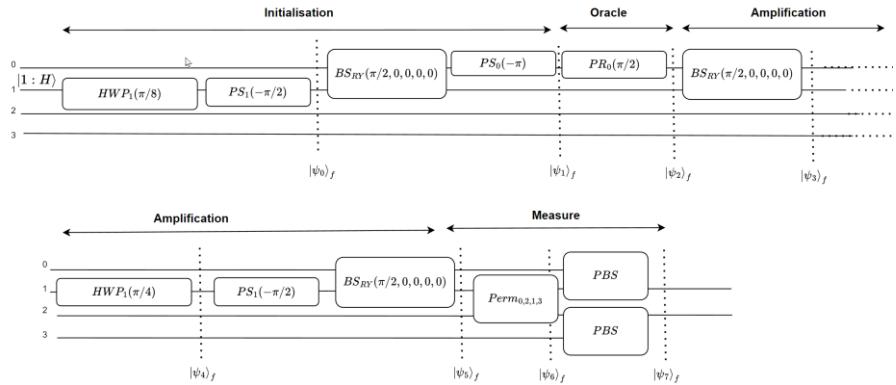


Figure 1. Photonic Polarized Grover Implementation

Table 2: A polarization-based encoding

Qubit encoding	Fock state encoding	Qubit encoding	Fock state encoding
$ 00\rangle$	$ 0, 1:H\rangle_f$	$ 10\rangle$	$ 1:H, 0\rangle_f$
$ 01\rangle$	$ 0, 1:V\rangle_f$	$ 11\rangle$	$ 1:V, 0\rangle_f$

3 Concluding remarks

Photon polarization-based circuit provides another approach to design quantum circuits relying on components specific to polarization. The major drawback of photonic circuits, particularly with regard to CNOT gates, can be circumvented through the use of circuits that leverage polarization. However, the circuits thus obtained introduce new challenges during the readout process, as demonstrated with Grover's algorithm [2].

References

- [1] Isaac L. Chuang & Yoshihisa Yamamoto, Simple quantum computer, Physical Review A 52, 3489 (1995). <https://doi.org/10.1103/PhysRevA.52.3489>
- [2] Bombardelli M., G. Fleury, P. Lacomme and B. Velpsecu. Foundations of photonic quantum computation. arXiv:2509.04266