Towards controlled-phase gate for time-bin qubits

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A controlled-phase (C-Phase) gate is one of an essential quantum logic gates to realize a quantum computer [1]. It has been demonstrated that a C-Phase gate for photonic polarization qubits can be realized by a 1/3 polarization dependent beam splitter (PDBS) [1]. Here we propose a scheme of the C-Phase gate for time-bin qubits by using a two-input, two-output electro-optic switch based on a lithium niobate waveguide as shown in Figure 1(a). By changing the applied voltage, the switch can be used as a flexible beam splitter (BS) that can be configured at the frequency of up to several tens of GHz [2]. By operating the switch so that it works as a 1/3 beam splitter for the second pulse while passing through the first pulse, we can realize the function equivalent to the PDBS for time-bin qubits.

We experimentally confirmed that the switch can be operated as a variable BS for a specific pulse of a time-bin qubit. We prepared two time-bin qubits by passing through photons generated by a photon-pair source based on spontaneous parametric down-conversion through 1-ns delay interferometers. The photons were input into the switch, to which we applied appropriate voltage pulses at the temporal positions of the second pulse so that the switch worked as a 1/2 and 1/3 BS for the second pulse. The photons output from the switch are detected by single photon detectors for Hong-Ou-Mandel (HOM) interference [3] measurement for the second time slot. As shown in Figure 1(b), we observed a HOM interference with the visibilities of 0.94±0.01 and 0.77±0.03 for 1/2 and 1/3 BS cases, respectively. This result agrees well with the theoretical curves for the HOM interference with 1/2 and 1/3 BS.

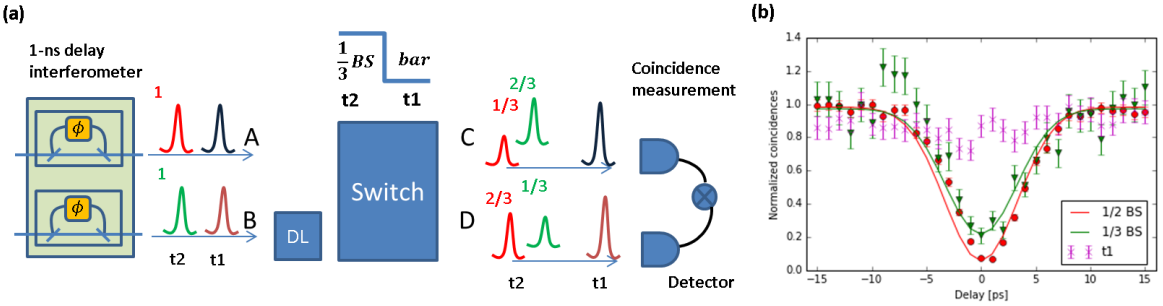

Figure 1: (a) The experimental setup for HOM interference by an electro-optic switch. (b) The experimental results that the switch flexibly worked as 1/2 (circles) and 1/3 (triangle) BS for the second time slot and the visibility are 0.94±0.01 and 0.77±0.03 (theory visibility is 1 and 0.8), respectively, and the first time slot (cross) did not show the dip.

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