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Analytical determination and single-photon validation of QHQ wave-plate settings for prescribed polarization transformations

We present an analytical method for determining the quarter-half-quarter (QHQ) wave-plate settings required to implement a prescribed $U(2)$ polarization transformation, up to a physically irrelevant global phase. The method addresses the inverse problem in which the desired operation is specified as a unitary matrix rather than by Euler angles or optical-element orientations. By explicitly removing the global phase, extracting the corresponding $SU(2)$ component, and determining the Euler parameters directly from the matrix elements, the prescription provides an analytical mapping from a target polarization transformation to experimentally accessible QHQ angles, without numerical optimization or iterative solution of nonlinear equations. We validate the method using heralded single photons generated by spontaneous parametric down-conversion. Polarization state tomography and direct reconstruction of the implemented transformations show high output-state fidelities and transformation infidelities on the order of 10^{-3} for a representative set of polarization operations. We further demonstrate the implementation of prescribed polarization evolutions by reconstructing fixed-axis and varying-axis trajectories on the Poincaré sphere. These results establish the proposed analytical prescription as a practical tool for implementing matrix-defined polarization transformations in classical and quantum optical experiments.

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