Efficient non-Hermitian wave-modulation protocol with a rapid parametric jump

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We propose an improved parametric passage protocol for faster exceptional point (EP)-bypass wave-modulation, enabling practical waveguide designs with shorter foot-print length. We achieve extinction ratio (ER) of 43 dB in a design with a length of only 15 coupling-length unit, which is smaller than 100 units required in the previous approach [1]. We validate the proposed protocol through rigorous numerical simulation of an exemplary InGaAsP waveguide structure.

We consider a two-level non-Hermitian system described by the following Hamiltonian

$$\mathbf{H}(\tau)=\begin{bmatrix} p(\tau)+iq(\tau) & 1 \\ 1 & -p(\tau)-iq(\tau) \end{bmatrix}.$$

The protocol we propose begins with an initial jump to near the EP, followed by a bypass around its vicinity before returning to the origin along the PT-symmetric line (see Fig. 1(a)). Due to the complex square-root geometry around the EP, mode switching is achieved by adiabatically bypassing the EP on the left results in the final state being a symmetric state, while adiabatically bypassing on the right leads to an anti-symmetric state.

After the parametric jump, the dynamic state evolves through a region with imaginary eigenvalue splitting. It gradually aligns with the amplifying eigenstate, effectively reproducing the outcome of fully adiabatic evolution. This adiabatic-like behavior requires precise control near the EP. To this end, we optimize the progression speed v using the speed-profile order J, defined as $v = v_{avg} N_v |\Delta\lambda|^J$. Figure 1(b) presents the ER map on the J-T plane, along with the total evolution time T.

We numerically demonstrate a coupled waveguide structure that implements this improved state-switching protocol. The design assumes InGaAsP core and SiO_2 cladding, forming an active integrated photonics platform. The EP-bypass process is realized by introducing imaginary refractive index profiles in the waveguide channels. Simulations are performed using the beam propagation method, and the results are shown in Figs. 2(a) and 2(b). The ER at a wavelength of 1550 nm is 15.2 dB (see Fig. 2(c)), and an ER exceeding 10 dB is maintained over a broad wavelength range from 1.48 μm to 1.62 μm (see Fig. 2(d)).

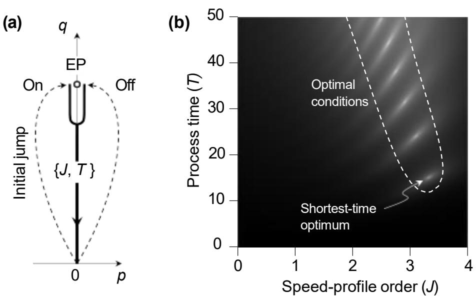

Fig. 1. Optimized parametric route and ER.

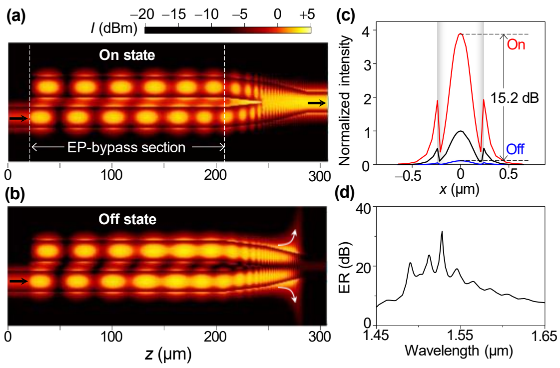

Fig. 2. Beam propagation method simulation.

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References

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