Exploiting $\mathcal{PT}$-symmetry for all-optical applications: Soliton steering in $\mathcal{PT}$-symmetric non-Kerr media

A. Govindarajan

Centre for Nonlinear Dynamics, School of Physics, Bharathidasan University, Tiruchirappalli-620 024, India

Non-Hermitian Physics - PHHPQ XVIII, ICTS, Bengaluru

ICTS INTERNATIONAL CENTRE for THEORETICAL SCIENCES

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Collaborator: Prof. M. Lakshmanan

Professor of Eminence and DST-SERB Distinguished Fellow

Plan of my talk

1. Why $\mathcal{PT}$-symmetric dimer?

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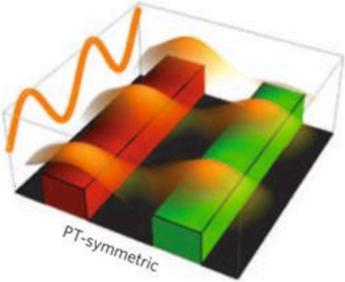
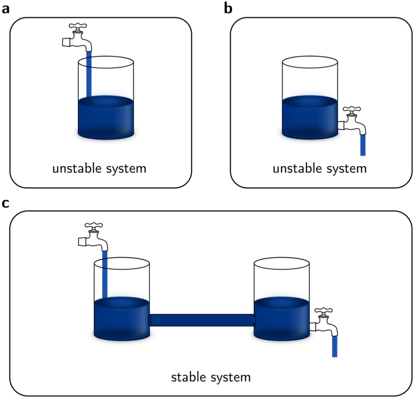
5. Conlusion



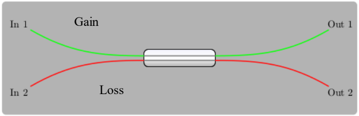


- Some intriguing applications like power oscillations[1] and non-reciprocal wave transport[2]
- What about steering dynamics?

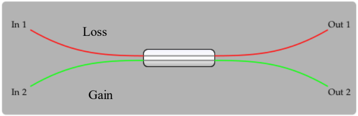
[1] S. Longhi, Phys. Rev. Lett. **103**, 2009.

[2] E. Rüter *et al.*, Nat. Phys. **6**, 2010.

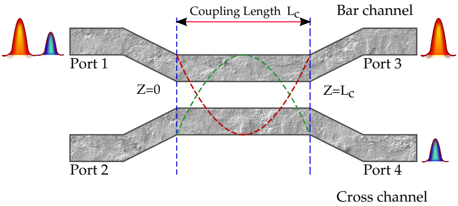
Model under study and soliton steering



(a) Type I $\mathcal{PT}$-symmetric coupler



(b) Type 2 $\mathcal{PT}$-symmetric coupler



(c) Steering dynamics of solitons in nonlinear directional couplers

Governing Equations:

- CNLSE in a normalized form[a] [b],

$$i\frac{\partial\Psi_1}{\partial\zeta}+\frac{1}{2}\frac{\partial^2\Psi_1}{\partial\tau^2}+|\Psi_1|^2\,\Psi_1-\gamma\,|\Psi_1|^4\,\Psi_1+\kappa\Psi_2=i\Gamma\Psi_1, \tag{1}$$

$$i\frac{\partial\Psi_2}{\partial\zeta}+\frac{1}{2}\frac{\partial^2\Psi_2}{\partial\tau^2}+|\Psi_2|^2\,\Psi_2-\gamma\,|\Psi_2|^4\,\Psi_2+\kappa\Psi_1=-i\Gamma\Psi_2. \tag{2}$$

[a] G. Burlak and B. A. Malomed, Phys. Rev. E **88**, 062904 (2013)
[b] G. Burlak, S. Garcia-Paredes, and B. A. Malomed, Chaos **26**, 113103 (2016).

System Parameters:

- **Second** and **third** terms respectively denote GVD and SPM
- $\gamma \approx$ quintic (non-Kerr) nonlinearity
- $\Gamma \approx$ the balanced gain and loss

Numerical Integration:

- Difficult to solve analytically (can't utilize methods like TMM, LA)
- Pseudospectral methods with $\kappa > \Gamma$ (unbroken $\mathcal{PT}$-symmetry)
- Initial conditions:

$$\Psi_1(\zeta = 0, \tau) = q\,\mathrm{sech}(\tau), \quad \Psi_2(\zeta = 0, \tau) = 0, \tag{3}$$

$$\text{Norms:} \quad P(0) = \int_{-\infty}^{\infty} |\Psi_1(0,\tau)|^2 d\tau,$$

$$P_j = \int_{-\infty}^{\infty} |\Psi_j(L_c,\tau)|^2 d\tau, \; (j = 1, 2). \tag{4}$$

Transmittance & Extinction Ratio

$$T_j = \frac{P_j}{P_1 + P_2} \quad , \quad (j = 1, 2). \tag{5}$$

$$\text{Xratio} = 10 \log_{10}\left(\frac{P_1}{P_2}\right) \tag{6}$$

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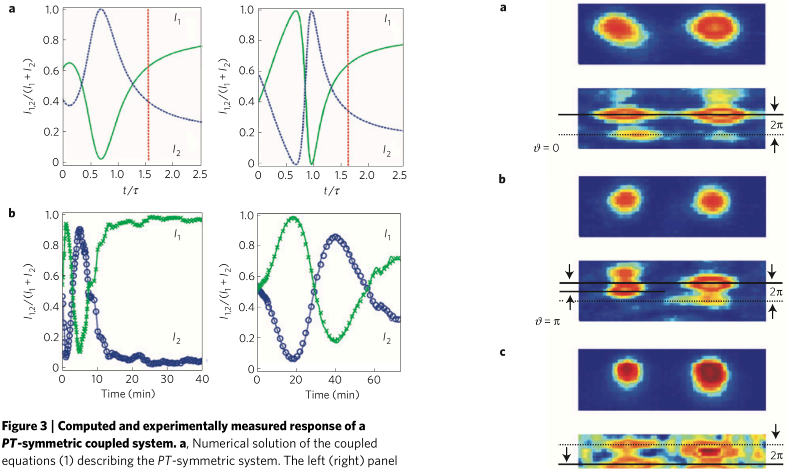


Figure 3 | Computed and experimentally measured response of a *PT*-symmetric coupled system. a, Numerical solution of the coupled equations (1) describing the *PT*-symmetric system. The left (right) panel

Role of $\mathcal{PT}$-Symmetry

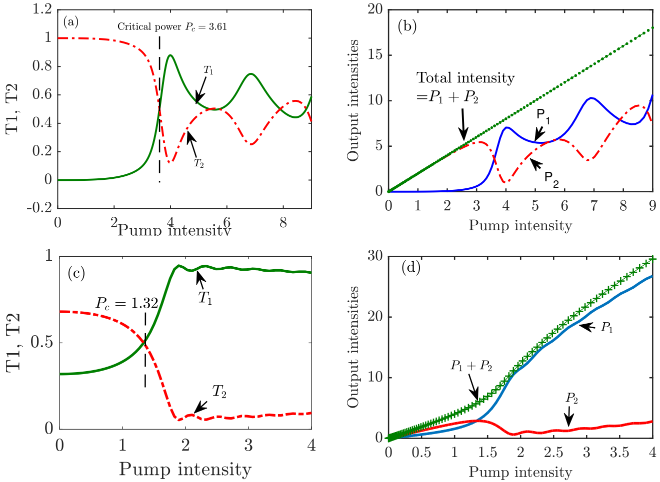


Figure 1: Steering dynamics of solitons in conventional couplers (top panels) and $\mathcal{PT}$-symmetric (type 1) couplers (bottom panels).

$\mathcal{PT}$-symmetry and Xratio

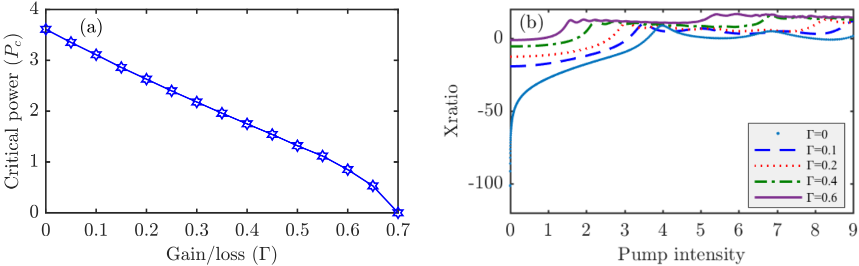


Figure 2: Relation between (a) the critical power and gain/loss parameter in (Γ, P_c) plane and (b) the extinction ratio as a function of pump intensity.

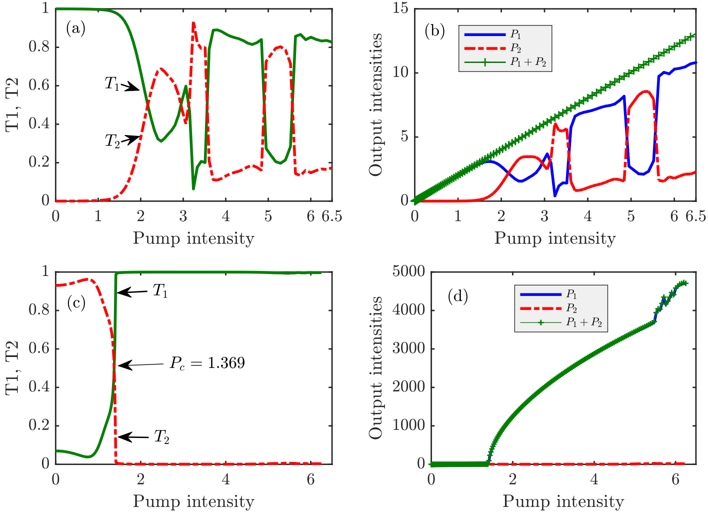


Figure 3: The same steering dynamics (as in the case of $\pi/2$ coupler) for 2π conventional couplers (top panels) and $\mathcal{PT}$-symmetric couplers (bottom panels).

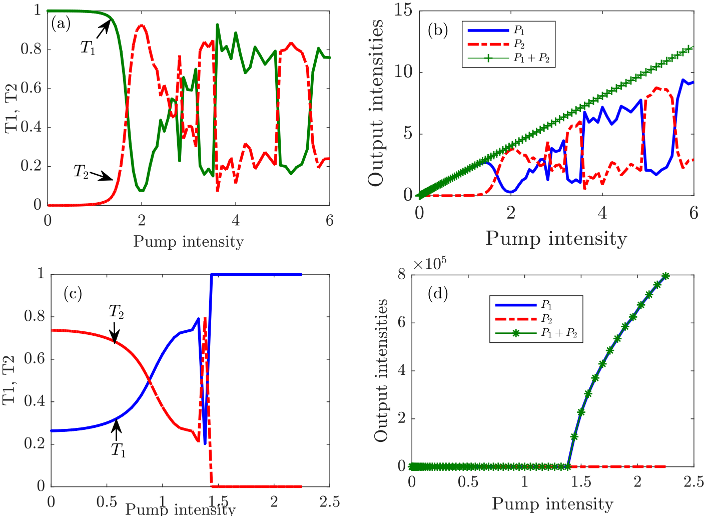


Figure 4: The steering dynamics for 4π conventional couplers (top panels) and $\mathcal{PT}$-symmetric couplers (bottom panels).

Type 2 $\mathcal{PT}$-symmetric coupler

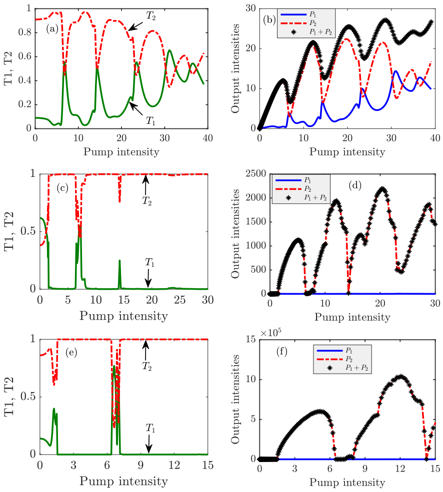


Figure 5: Transmittance and output intensities of solitons in the two channels of type 2 $\mathcal{PT}$-symmetric couplers for various coupling lengths. Top panel corresponds to $\pi/2$ coupler, center panel is for 2π and bottom panel refers to 4π coupler.

Tabulation

Table 1: Critical power for various lengths of different types of $\mathcal{PT}$-symmetric couplers.

Device length	Soliton input	Critical power for various types		
		Conventional	Type 1 $\mathcal{PT}$-coupler	Type 2 $\mathcal{PT}$-coupler
$\pi/2$		3.61	1.32	Incomplete
2π	sech(τ)	2.17	1.36	1.10*
4π		1.69	0.85	6.50*

* Indicates the first steering threshold intensity

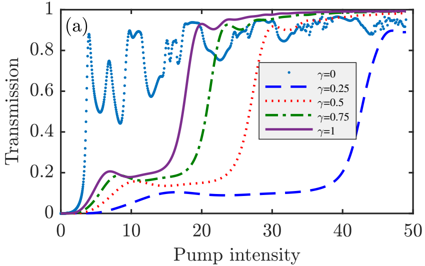


Figure 6: Influence of defocusing quintic nonlinearity on the steering dynamics of solitons in $\pi/2$ conventional couplers. Transmitted energy in (a) channel 1 and (b) channel 2 with the system parameters $\alpha = \Gamma = 0$.

In $\mathcal{PT}$-symmetric coupler

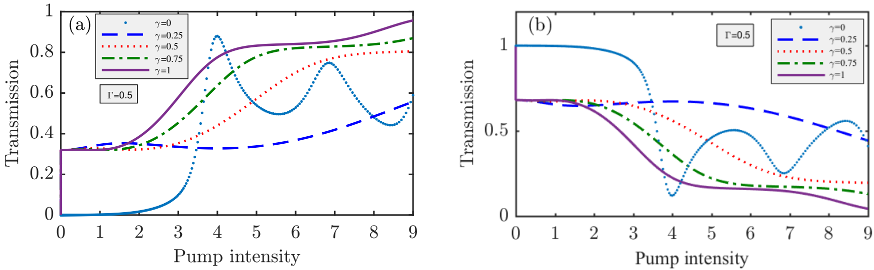


Figure 7: Plots showing the rapid variation of defocusing quintic nonlinearity on the transmittance of solitons in (a) the first channel and (b) second channel of $\pi/2$ $\mathcal{PT}$-symmetric couplers. Here we fixed the gain/loss parameter as $\Gamma = 0.5$.

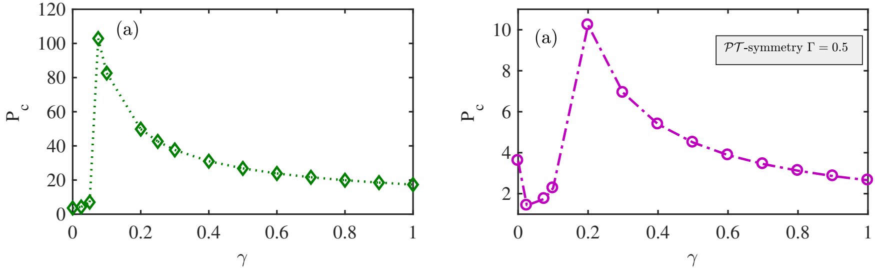
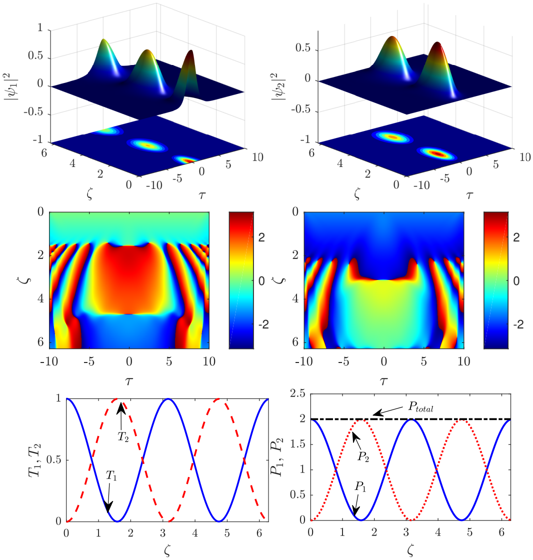


Figure 8: Relation between the critical power and defocusing nonlinearity in (γ, P_c) plane for (a) conventional and (b) $\mathcal{PT}$-symmetric couplers. The parameters are same as in Fig. 7.

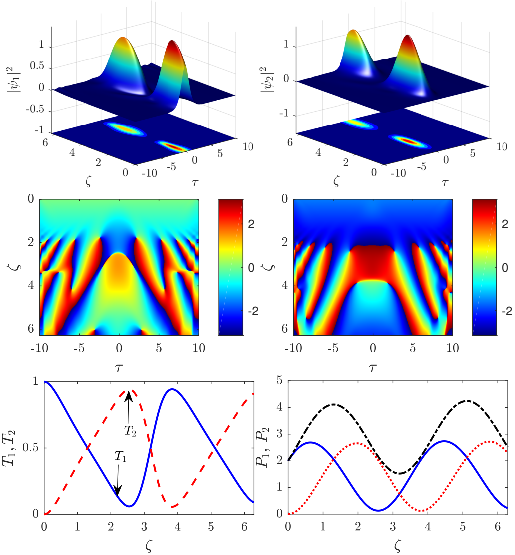
Spatio-temporal dynamics in conventional coupler



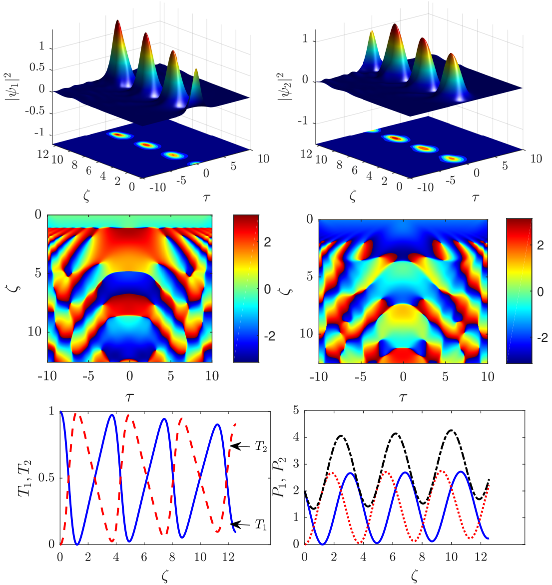
- Energy route of the form $In_1 \to Out_3$.
- Periodic transfer with constant (total) power

In Type I $\mathcal{PT}$ coupler

- A new energy route of the form! $In_1 \rightarrow Out_4$.
- Power of the soliton pulse gets amplified
- Coupling length is increased



In Type 2 $\mathcal{PT}$ coupler



Concluding Remarks

- To wrap-up, we have numerically demonstrated the steering dynamics of optical (bright) solitons in $\mathcal{PT}$-symmetric couplers by taking into account the cubic-quintic nonlinearities.
- Have identified that the 'phenomenological' $\mathcal{PT}$-symmetric effect dramatically reduces the steering critical power with a sharp steering in the competing $\mathcal{PT}$-symmetric couplers, which was further corroborated by the evolution dynamics.
- Ramifications of such phenomenological $\mathcal{PT}$-symmetric driven couplers may open up new possibilities of enabling ultralow- power and ultrafast all-optical soliton switch in the light-wave communication systems.
- Also, the $\mathcal{PT}$-symmetric dimer can be exploited for other potential applictions such as all-optical logical gates and soliton compression, which are being currently investiged.

Thank You!

ANY QUERIES