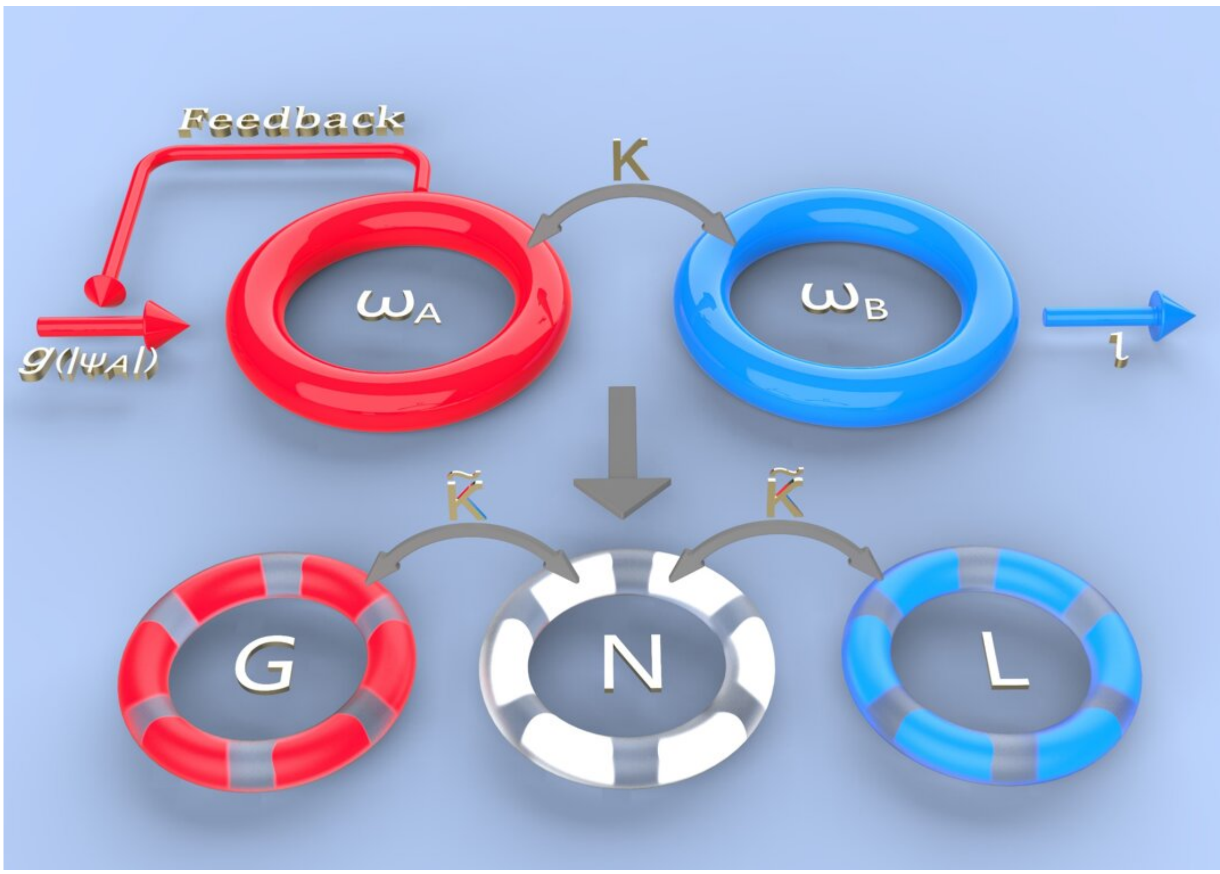
A nonlinear exceptional nexus with an ultra-enhanced signal-to-noise ratio

December 22 2022

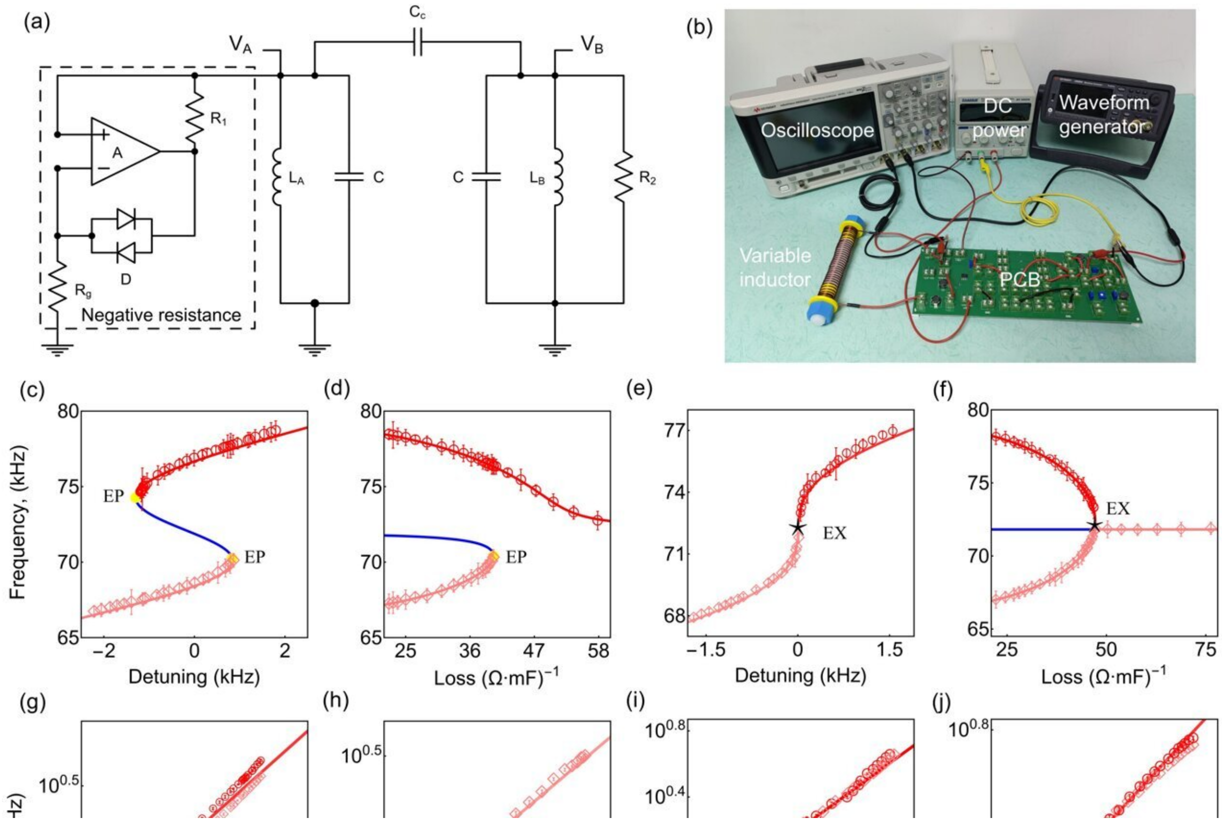


The upper panel shows two coupled resonators. The left resonator (red) has nonlinear saturable gain, and the other resonator (blue) has linear loss. Such a nonlinear non-Hermitian system can be mapped into a PT symmetric three-resonator system as shown in the lower panel with linear gain (G), neutral (N) and loss (L) resonators. Credit: Science China Press

Prof. Duanduan Wan and Prof. Meng Xiao at the School of Physics of Wuhan University recently published a study in the journal *National Science Review*. Their work provides a simple while intuitive example, demonstrating with both theory and circuit experiments an "exceptional nexus" ("EX"), a higher-order exceptional point (HOEP). This HOEP is realized within only two coupled resonators with the aid of nonlinear gain. Moreover, such a HOEP exhibits an ultra-enhanced signal-to-noise ratio.

Exceptional points (EPs) underlie the recent advances in non-Hermitian physics, such as sensitivity enhancement, skin effects, and mode braiding. Over the last few years, there has been an ongoing debate about whether EPs can improve the sensor's performance or not.

Possible arguments include stringent parameter requirements, fundamental resolution limits, and noise amplification near the EPs. Facing these challenges, researchers intend to conclude that EPs, even higher-order EPs (HOEPs), enhance responsivity instead of signal-to-noise ratio. Here, this team from Wuhan University shows that such a nonlinearity enabled HOEP exhibits not only diverging responsivity but also diverging signal-to-noise ratio.



(a), Circuit used for experimental verification, showing the inductors (L), capacitors (C), resistors (R), diodes (D) and amplifier (A). (b) Photo of the experimental setup. (c-f), Measured resonance frequencies (open circles and diamonds) of the system together with the steady state eigenfrequencies from the simulations (solid lines). (g-j) show the critical behavior near the corresponding EPs and EX in (c-f), respectively. The solid lines are the theoretical predictions. The estimated experimental errors (standard deviation obtained from 8 independent measurements) in (c-j) are smaller than the marker sizes. For demonstration purposes, we exaggerate the error bars by a factor of 100, 100, 50, 50, 10, 10, 10 and 10 in (c-j), respectively. (k-n) show the corresponding (SNR)-1 for different detuning and loss values and the cyan background represents the theoretical fitting. Credit: Science China Press

Exploring the nonlinear gain saturation in non-Hermitian systems, this team demonstrates with both theory and circuit experiments an exceptional nexus (EX), a HOEP, within only two coupled resonators (see the first image). Intriguingly, the above-mentioned difficulties encountered for other EPs in sensing can be naturally reconciliated due to the exquisite dimension correlation in this nonlinear system. Moreover, the signal-to-noise ratio is significantly improved in the proximity of HOEP (see the second image).

This result can have significant instant impacts on the fundamental understanding of the exceptional singularities of nonlinear non-Hermitian systems, and may open new avenues for applications such as ultrasensitive measurements.

More information: Kai Bai et al, Nonlinearity enabled higher-order exceptional singularities with ultra-enhanced signal-to-noise ratio, *National Science Review* (2022). DOI: 10.1093/nsr/nwac259

Provided by Science China Press