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Guided-wave devices with fixed losses inspired by PT-symmetry and their spectrum singularity

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Abstract- Guided-wave devices with plasmonic-type fixed losses can be adapted to exploit the singular point behavior well known for exact PT symmetric guides. Coupled guides having fixed losses and variable gain fail to exhibit a singular point in their eigenvalues if the guides! effective indices coincide. We show how to "heal# this situation and restore singularity by detuning among the guides. We also present a frame inspired by Kogelnik!s representations of alternate $\Delta\beta$ couplers to usefully account for several configurations.

We investigate the possible benefits of guided wave devices, such as couplers made of two coupled guides, but inspired by the PT symmetric configuration which is well known to produce a singular point in the eigenvalue spectrum evolution vs. the gain/loss parameter. In actual coupled waveguides, it is generally delicate, if not impossible, to impose gain and losses accurately while maintaining a good mode coupling between the two guides. Therefore, it is tempting to investigate the capability to retain the essential features of the singularity of eigenvalues with a more practical guide that features only fixed losses, and notably a plasmonic waveguide.

In the simplest 1D coupled-wave view, we first remark that the singularity is maintained for a guide with fixed losses ($g= -|g|$, of course coupled to a gain guide), but that the singular point itself lies at zero modal gain (γ=0) only if the coupling strength is related to the fixed losses according to the rule $|g| =\kappa$. The transfer function can then be plotted (Fig.1(a)) in a map whose axis are (L, $|g|/\kappa$), i.e. guide length L and gain to coupling ratio. Compared to a similar map for an exact PT system, most major features are preserved [1]. The tracks of the underlying eigenvalues are indicated below these figures.

However, if we model actual coupled waveguides, e.g. a plasmonic and a dielectric waveguide, the track of eigenvalues in the complex plane avoids the singularity by a variable amount. We interpret this effect as a complex coupling, the coupling constants are affected by the variable gain in the concerned waveguide.

Correspondingly, some of the transitions manifested in Fig.1 are smoother than they would be ideally. Thus, it would be advantageous to "heal# the waveguides in such a way as to restore the singularity.

We showed very recently [2] that this is simply done by detuning the two waveguides. Then, the interplay of variable gain with both the real and imaginary parts of the system!s eigenvalues can lead to a "compensation#, causing the eigenvalues trajectories to experience a perfect singularity.

We will give a graphical interpretation of this "healing# mechanism, and we will exemplify its operation in several model cases, with either model dielectric guides or more realistic configurations involving plasmons or involving the recently proposed hybrid plasmonic waveguide geometry that we have termed "PIROW# (Plasmonic Inverse-Rib Optical Waveguide) [3].

In the last part of this talk, we will attempt to present a variant of PT symmetric guides that is analog to Kogelnik!s alternate-$\Delta\beta$-couplers presented decades ago [4]. The main merit of this approach and of the associated diagrams in the (L, $|g|/\kappa$) plane is to show how the extra complexity allows both "cross# and "bar#

states in a coupler that does *not* operate at the right length, coupling, or wavelength by modifying the gain/loss parameters. Indeed "bar# and "cross# refer to passive waveguides and these denominations should be generalized for PT symmetric systems, as we shall explain.

As a hint, we note that one essential feature of the commutation diagram for a PT system is the genesis of two branches originating from each singular cross state at the g=0 axis. These two branches open the possibility to either get the usual "reciprocal# cross-bar switching found in conventional passive coupled waveguides, or get an asymmetric switching that can be fruitfully exploited to implement a dynamical buffer memory as proposed by Kulishov in 2005 [5].

Thus, the introduction of alternating gain/loss sections along the propagation direction in the variant PT system leads to an extra feature in the transfer diagram. As more alternating PT sections are defined, regularly spaced stripes of high gain regions emerge close to the G=0 axis inside regions that featured lower gain in the non-alternating case of Fig. 1(a). The origin of this phenomenon and its potential applications will be discussed.

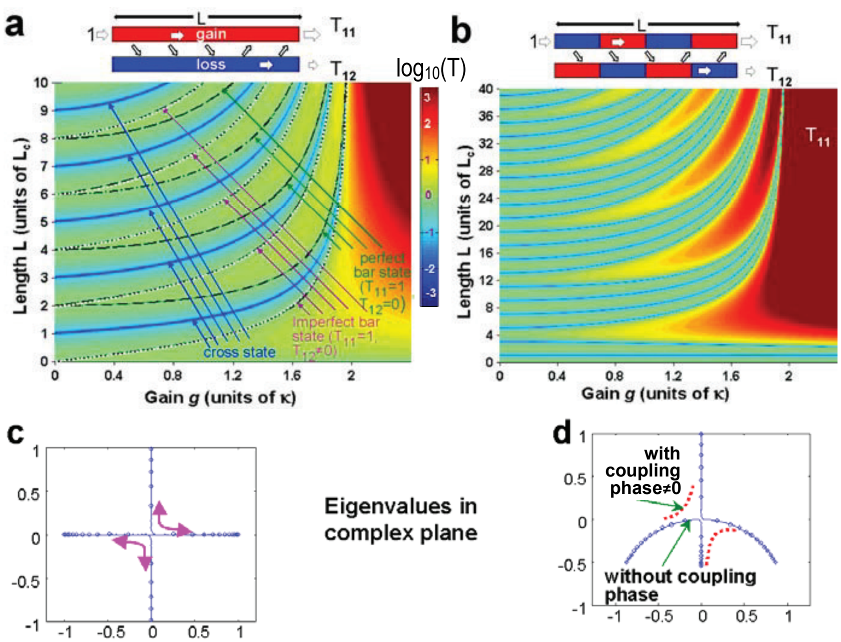

Figure 1 :
(a) Ideal transfer diagram of a PT symmetric system : the color map is that of T_{11};
(b) Similar transfer diagram but with 4 alternating PT sections coupler.
The two bottom graphs (c,d) show the respective eigenvalue evolutions in the complex plane. The presence of a coupling phase causes an avoided crossing, thus no good operation window unless the fixed losses are "healed".

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