1. Introduction

Bound states in the continuum (BICs) were predicted by von Neumann and Wigner at the dawn of quantum mechanics [1]. They found that states embedded in the continuum band keep bounded for a particular kind of oscillating potential. Recently, interest in BICs investigation has been increasing due to the observation of these types of states in photonic systems. Since interference phenomena takes place in electronic systems in analogy with the photonic ones, the inherent possibility of the presence of BICs emerges [2–7].

On the other hand, the Majorana fermions (MFs) were first predicted by Ettore Majorana in 1937, which are fermionic particles that are their own antiparticles [8–10]. Since then, there have been several efforts to discover this kind of particle. A natural MF candidate is the neutrino, however, up to now, there is no evidence to support it. In the context of condensed matter physics, Kitaev predicted the realization of localized MFs, Majorana bound states (MBSs), at the ends of a semiconductor-superconductor nanowire in topological phase, the so-called Kitaev chain [11, 12], in which both MBSs placed at opposite ends can interact with a coupling strength $\epsilon_M \propto \exp(-L/\zeta)$, where $L$ is the Kitaev chain length and $\zeta$ the superconducting coherence length. Nowadays, different experiments suggest that this theoretical prediction has been confirmed by means of physical realization of the Kitaev proposal [13–18]. Recently, the investigation of MBSs has had a great deal of attention as these states are seen to be useful in quantum computation implementations since they satisfy non-Abelian statistics and can be manipulated with braiding operations [11, 12, 19–28]. In quantum dot (QD) systems, a special signature of the presence of MBS was established as a half-integer conductance at zero energy [29] when the MBS is side-coupled with the QD. Later, Vernek et al [30] have shown that this zero-bias anomaly is due to MBS leaking into the QD, and it is robustly pinned against changes in QD energy level, which has recently been verified [31]. In this scenario, a proposal of Majorana-based qubit readout technology was carried out using BICs mechanisms in an embedded QD between topological superconductors (TSCs) [32], and recently a theoretical encryption device based on BICs is available in a TSC coupled to a double QD structure [33]. Besides, a spin-dependent coupling between QDs and topological quantum wires has been proposed [34].
Multiple QDs systems have the possibility to achieve BICs arising naturally from interference phenomena [3]. However, there is no information on how this kind of non-topological BIC behaves in interplay with MBSs leaking phenomena. In this work, we address the latter and calculate the formation of BICs poisoned by MBS in a triple QD system with two side-coupled topological superconductors (TSCs) nanowires. The MBS have topological characteristics, in contrast with the BIC arising from the hybridization of the isolated triple QD array. Then, both kinds of bound states coexist in our system. Our results show the buildup of BICs with topological characteristics due to the presence of the MBSs. For symmetric QDs levels, the presence of MBSs has a projection in the electronic characteristics due to the presence of the MBSs. For symmetric QDs and (5) transform to

$$H_{\text{dot-M}} = \left( \lambda_0 d_{-1} - \lambda_d d_{+1} \right) (f_0^d + f_0^u) + \frac{1}{\sqrt{2}} \left( \lambda_d d_{-1} - \lambda_0 d_{+1} \right) (f_0^u + f_0^d), \quad \text{(6)}$$

The main contribution of the leads is to include a self-energy $\Sigma_{\alpha}(\epsilon)$ for electrons (holes). In the wide-band approximation, it is energy-independent, such as $\Sigma_{\alpha}(\epsilon) = -\Pi_{\alpha}(\epsilon)$, and it fulfills electron hole symmetry, hence $\Gamma_{\alpha}(\epsilon) \equiv \Gamma_{\alpha}^\dagger$. We consider symmetric QD-leads coupling $\Gamma_{\alpha} \equiv \Gamma/2$, so $\Gamma_{\alpha} = \Gamma$. In order to obtain the transport quantities of interest we use

$$H_{\text{M}} = \epsilon_{\alpha}^0 \eta_{\alpha}^1 + \epsilon_{\alpha}^1 \epsilon_{\alpha}^1 \eta_{\alpha}^1, \quad \text{(4)}$$

where $\epsilon_{\alpha}^1$ is the electron creation (annihilation) operator with momentum $\mathbf{k}$ and energy $\epsilon_{\alpha}(\mathbf{k})$ in the lead $\alpha = L, R$. $d_{\alpha}^\dagger (d_{\alpha})$ is the electron creation (annihilation) operator in the $\alpha$th QD, with single energy level $\epsilon_\alpha$, $t$ is the inter-dot coupling and $V_\alpha$ is tunneling hopping between the lead $\alpha$ and QD$_0$.

The two last terms in the Hamiltonian, $H_{\text{M}}$ and $H_{\text{dot-M}}$, correspond to MBSs and their couplings with QDs, respectively. They are given by

$$H_{\text{dot-M}} = \left( \lambda_0 d_{-1} - \lambda_d d_{+1} \right) (f_0^d + f_0^u) + \frac{1}{\sqrt{2}} \left( \lambda_d d_{-1} - \lambda_0 d_{+1} \right) (f_0^u + f_0^d), \quad \text{(5)}$$

where $\eta_{\beta}^\dagger$ denotes the MBS operator, which satisfies both $\eta_{\beta}^\dagger = [\eta_{\beta}^\dagger]^\dagger$ and $\{\eta_{\beta}, \eta_{\beta'}^\dagger\} = \delta_{\beta,\beta'} \delta_{l',l}$. In addition, $\lambda_{\alpha}^0$ is the tunneling coupling between $d_{\alpha}^\dagger \eta_{\beta}^\dagger$ and the QD$_{-1}(0)$. The strength between two MBSs in the same TSC, where $E_0$ denotes the wire length and $\zeta$ is the superconducting coherence length. Without loss of generality, we fixed $\lambda_0 = \lambda_d^\dagger = |\lambda_d|$ and $\lambda_\alpha = |\lambda_\alpha| \exp[i\theta/2]$, where $\theta$ is the phase difference between both TSCs.

A useful way to treat the system analytically is by writing each MBS as a superposition of regular fermionic operators as $\eta_{\beta}^\dagger = (f_l + f_l^\dagger)/\sqrt{2}$ and $\eta_{\beta} = -i(f_l - f_l^\dagger)/\sqrt{2}$ which satisfy both $\{f_l, f_{l'}\} = \{f_{l'}^\dagger, f_l^\dagger\} = 0$ and $\{f_l, f_{l'}^\dagger\} = \delta_{l,l'}$. Then, (4) and (5) transform to

$$H_{\text{M}} = \epsilon_{\alpha}^0 \eta_{\alpha}^1 + \epsilon_{\alpha}^1 \epsilon_{\alpha}^1 \eta_{\alpha}^1, \quad \text{(4)}$$

Figure 1. Model setup: crossbar-shaped QD-TSCs system. A triple QD array (green) coupled to two normal leads, labeled as L and R (solid gray), and two TSCs (gray tones) $u$ and $d$, each hosting two MBSs (red), $\eta_{\alpha}^1$ and $\eta_{\alpha}^2$.

The behavior of the MBSs inheriting their topological properties to the BIC state can be seen by looking the zero energy states, which when are strictly degenerated, these MBSs are hiding the BIC. We show that by manipulating the MBSs splitting, i.e. tuning the effective topological length of the wire [19], the BIC can be unveiled/hidden. We believe our findings could be useful to implement a switching device, since we can control the access to the BIC to write and/or read information unveiling it, while the existing information can be protected denying the access covering it, just by tuning the coupling strength between MBSs localized in the same topological wire.

This paper is organized as follows: section 2 presents the system Hamiltonian and method used to obtain quantities of interest; section 3 shows the results and the corresponding discussion, and finally, the concluding remarks are presented in section 4.

### 2. Model

The system under study considers a crossbar-shaped form by a linear array of three QDs, two normal leads and two TSCs hosting MBSs at its edges. The central QD (QD$_0$) is connected with both leads. Each QD located at the end of the array has a side-coupled TSC, as shown in figure 1.

We model the system with an effective low-energy Hamiltonian, which has the form $H = H_{\text{leads}} + H_{\text{dot}} + H_{\text{dot-leads}} + H_{\text{M}}$, where the first three terms on the right side correspond to the regular electronic contribution, given by

$$H_{\text{leads}} = \sum_{\alpha, \mathbf{k}} \epsilon_{\alpha}(\mathbf{k}) \epsilon_{\alpha}^\dagger(\mathbf{k}) \epsilon_{\alpha}(\mathbf{k}), \quad \text{(1)}$$

$$H_{\text{dot}} = \sum_{\alpha, \mathbf{k}} \epsilon_{\alpha}(\mathbf{k}) d_{\alpha}^\dagger d_{\alpha} + \sum_{j=-1}^0 t d_{\alpha}^\dagger d_{\alpha+1} + \text{H.c.}, \quad \text{(2)}$$

$$H_{\text{dot-leads}} = \sum_{\alpha, \mathbf{k}} V_\alpha(\mathbf{k}) \epsilon_{\alpha}^\dagger(\mathbf{k}) \epsilon_{\alpha}(\mathbf{k}) + \text{H.c.}, \quad \text{(3)}$$
the Green’s function formalism. The full system retarded Green’s function $G'(\omega)$ is obtained by means of direct inversion, i.e. $G'(\omega) = [\omega - H]^{-1}$, where $\omega$ is the energy and $H$ the system Hamiltonian, both in matrix form. The guidelines for the procedure are presented in the appendix. In this scenario the transmission probability through QD0 can be written as $T(\omega) = -\Gamma \text{Im}[G'_0(\omega)]$, with $G'_0$ being the QD0 retarded Green function. Finally, the local density of states (LDOS) can be written as $\text{LDOS}_0(\omega) = -(1/\pi)\text{Im}[G'_j(\omega)]$ for QDs.

Throughout the next sections, we focus on these quantities to explore the coexistence and interplay of BIC with MBSs.

3. Results

3.1. Without phase difference, $\theta = 0$

Before going into the MBS-BIC interplay results, an analysis of the eigenvalues is performed for the disconnected (without leads) system appearing in figure 1, for the case without phase difference. These are closely related to the full system Green’s function poles, and give reliable information about energy localization of the states. For a particular case, assuming $|\lambda_{ud}(\Delta)| = \lambda$, $\epsilon^{ud}(\Delta) = \epsilon_m$, $\epsilon_0 = \pm \Delta$ and $t_1 = t_{1-} = t$ the eigenvalues can be written out as follows

$$\omega_i = 0,$$

$$2 \left[ \omega_i^2 \right] = \epsilon^2_m + \Delta^2 + 2(\lambda^2 + \Gamma^2) + t^2 \pm \left( \epsilon^2_m + \Delta^2 \right) \left[ \epsilon^2_m + \Delta^2 + 4(\lambda^2 + \Gamma^2) \right] - 4\epsilon^2_m (\Delta^2 + 2\Gamma^2) + 4(\lambda^2 \pm \Gamma^2)^2)^{1/2},$$

where the energy $\omega_i = \epsilon_0 = 0$ has double degeneracy, while the other eight energies are contained in $\omega_i$, each corresponding to a particular combination of $+$ and $-$ signs. For a fixed $\Delta = 0$, the following energies are computed from (9) as

$$\omega_i^{+,-}(\Delta = 0) = \pm t\sqrt{2},$$

$$\omega_i^{-,-}(\Delta = 0) = \pm \sqrt{\epsilon^2_m + 2\lambda^2},$$

$$2 \left[ \omega_i^{\pm,-}(\Delta = 0) \right] = \epsilon^2_m + 2(\lambda^2 + \Gamma^2) \pm \sqrt{\epsilon^2_m + 2(\lambda^2 + \Gamma^2)^2 - 8\epsilon^2_m \Gamma^2},$$

where it can be noted that if the MBSs overlapping vanishes, $\epsilon_m = 0$, two of the four possibilities of (12) take the zero value.

In what follows, all the results are performed at temperature $T = 0$, in which the conductance is $G(\epsilon_F) = (e^2/h)T(\omega = \epsilon_F)$, with $\epsilon_F$ being the Fermi energy, and all the energy parameters are given in units of fixed $\Gamma = 1$ meV. Throughout this work, the inter dot couplings are fixed at $t_j = \Gamma$ and a weak QD-TSC coupling $|\lambda_{ud}(\Delta)| = \lambda = 0.1 \Gamma$ is considered.

First we display the transmission across QD0 and LDOS for QD $\pm 1$ in figure 2, in which we use a long wire limit, i.e. $\epsilon_{ud}(\Delta) = 0$. The transmission shows two broad lateral maxima (inset in panel (a)) due to the QDs hybridization (see for instance (10)) and it is clear that the zero energy half-integer is still observed, solid blue lines in panel (a). Interestingly, this behavior is evidence that the leaking of the two MBSs into the central QD occurs even through the two lateral QDs. The LDOS for lateral QD $\pm 1$ show two symmetric BICs placed at energies $\pm \sqrt{2}\lambda$, which are given by (11). These states

![Figure 2](image-url)
correspond to hybridized MBSs, which do not show apparent projection in the transmission.

To explore the previous behavior in more detail, we introduce a small asymmetry energy parameter by setting the gate voltages of the lateral QDs as $\varepsilon_{\pm}=\pm\Delta$. For the isolated QDs case ($\lambda=0$), this allows revealing a BIC in the transmission, coming from the hybridization of QDs states, whose width is proportional to $\Delta$. In our case ($\lambda \neq 0$), we use it to study the interplay of the different phenomena.

Figure 3 displays the transmission profile out of the long-wire limit, considering $\varepsilon_M^{u(d)}=\varepsilon_M$, i.e. symmetrical MBSs overlapping. In figures 3(a) and (c) the cases with fixed zero-energy ($\omega=0$) are considered. From this we can observe that as $\varepsilon_M$ is turned on, the transmission around $\varepsilon_0=0$ begins to increase continuously from the half-integer transmission to the unitary limit. Besides, in figures 3(b) and (d) we explore the transmission considering $\varepsilon_d=0$. In this case, by moving away from $\varepsilon_d=0$ the transmission begins to unveil states placed at energies given by (8) and (9). It is important to note that these states do not appear in the transmission for the fully symmetric case ($\Delta=0$), as shown in figure 2. This behavior of the transmission for particular energy $\omega=0$ represents a signature of the existence of the BIC belonging to QDs, which remains hidden/covered by the MBSs leakage when $\varepsilon_M=0$ and being gradually exposed as $\varepsilon_M$ increases.

Furthermore, in figure 4 we compare the behavior of the transmission with the eigenvalues of the disconnected system. Figure 4(a), which is a zoom out of figure 3(b), displays the evolution of transmission shape with $\varepsilon_M^{u}$, while figure 4(b) shows the eigenvalues using $\Delta=0$ ($\varepsilon_{\pm}=0$) given by (8), (11) and (12). We focus in a region near to zero energy, where only those eigenvalues that can be attributed to BICs were considered. Therefore, figure 4(b) shows the behavior of six of these states as a function of $\varepsilon_M$, and the other four states occur at energies far from zero, at $\sqrt{2}\Gamma$. With a small value of $\Delta$, i.e. $\Delta^2/\Gamma^2 \ll 1$, the numeric resemblance is remarkable, and the relation between transmission resonances and eigenvalues allow us to predict exactly for which energy a state can be accessed due to its projection on the transmission curve.

It is important to highlight how the initially non-topological BIC can be suppressed/covered by the influence of the MBSs leakage, thus it is acquiring topological characteristics. Apparently, this poisoning behavior only allows protection of the BIC prohibiting its projection in transmission whenever both TSCs nanowires are long enough to reach $\varepsilon_M=0$. From this point we addressed the robustness of this behavior for non-symmetric TSCs. In order to give a further analysis of the system, in figure 5 a transmission color map regarding $\varepsilon_0$ and $\omega$ is shown, where we start from the $\varepsilon_M^{d}=0$ case to finish in $\varepsilon_M^{d}=0.03\Gamma$, passing through different $\varepsilon_M^{d} \neq \varepsilon_M^{u}$ combinations. In figure 5 left and right panels, we fixed $\Delta=0$ and $\Delta=0.01\Gamma$, respectively. As expected, in long-wire limit $\varepsilon_0^{d}=0$ a robust zero energy half-integer transmission is shown in figures 5(a) and (b). On the other hand, from figures 5(c) and (d), if one of the TSC leaves the long wire limit ($\varepsilon_M^{d}=0.03\Gamma$), the half-integer transmission splits, at $\omega \sim \pm \epsilon_M^{d}$ (due to the complexity of the eigenvalues expressions the exact value must be computed numerically) regardless $\Delta$. At zero energy ($\omega=0$), the transmission becomes strongly dependent of $\Delta$. For $\Delta=0$, the expected zero energy resonance is entirely suppressed, being blocked by the corresponding side coupled QD, while $\Delta \neq 0$ restores the zero energy half-integer resonance. As a consequence, at this point the BIC is still poisoned by the leaked MBS from the TSC that remains in the long-wire limit ($\varepsilon_M^{d}=0$). In the next four panels, figures 5(e)–(h), both TSCs leave the long wire limit. In the case of panels (e) and (f) we consider $\epsilon_M^{d}/\epsilon_M^{u}=2$, for
which the two lateral QDs keep a similar behavior (regardless $\Delta$). At zero energy for $\Delta = 0$, the corresponding state does not show any projection in transmission, while for $\Delta \neq 0$ the MBS leakage and the BIC can interplay, being a poisoned BIC. At this point, it reaches an integer transmission around $\varepsilon_0 = 0$, but it is worth mentioning that its emergence is continuous, as we showed before. Finally, in panels (g) and (h), when both TSCs reach the same wire length ($\epsilon_{\text{M}}^{\text{u}(d)} = \epsilon_{\text{M}} = 0.03 \Gamma$), these two states are placed at $\omega = \pm \epsilon_{\text{M}}$ and this value can be obtained from (9) or in an approximated way by (12). Just like the case discussed above, the BICs remain robust around $\varepsilon_0 = 0$. Therefore, we conclude that the BIC arising by interference phenomena in QDs with $\Delta \neq 0$ is poisoned whenever at least one of the TSCs keep the long wire limit, i.e. $\epsilon_{\text{M}}^{\text{u}} = 0$ and/or $\epsilon_{\text{M}}^{\text{d}} = 0$.

At this point, it is clear that the central BIC have new features, since just set $\Delta \neq 0$ is not enough to expose it in the transmission. Let us focus on figure 5 right panels, where $\Delta = 0.01 \Gamma$. In a very narrow energy region around $\omega = 0$, i.e. from $\omega - \delta \omega/2$ to $\omega + \delta \omega/2$ with $\delta \omega/|\omega| \ll 1$, the transmission can be expressed in an approximated way as

$$T(\omega) \sim \frac{1}{2} \left( \frac{\tilde{\gamma}^2}{\omega^2 + \tilde{\gamma}^2} + 1 \right),$$

(13)

where $\tilde{\gamma}$ is the state width, which satisfies

$$\tilde{\gamma} \propto \frac{\Delta^2}{\Gamma} \left( \frac{1}{\Gamma} \frac{\epsilon_{\text{M}}^{\text{u}(d)} \epsilon_{\text{M}}^{\text{d}(u)}}{\epsilon_{\text{M}}^{\text{u}} + \epsilon_{\text{M}}^{\text{d}}} \right)^{3/2}.$$  

(14)

From the above expression, it is evident that this state becomes a BIC in the limit $\epsilon_{\text{M}} = 0$, with a Dirac $\delta$–function in the LDOS of the side coupled QD, with no contribution in transmission. A way to manipulate $\epsilon_{\text{M}}$ is by using a keyboard of locally tunable gates beneath the TSC nanowire [19], where the effective topological wire length, and then the separation between MBSs, can be manipulated by transporting the MBS in the free end of the TSC (for instance $\eta_{\text{M}}^{\text{u}(d)}$) to a position closer/further from the fixed MBS, coupled to the corresponding side QD ($\eta_{\text{M}}^{\text{u}(d)}$). This setup will allow a measurement of the poisoned BICs.

Figure 5. Transmission $T$ contour plot as a function of the energy $\omega$ and central QD energy level $\varepsilon_0$ for different values of $\Delta$ and $\epsilon_{\text{M}}^{\text{u}(d)}$.

Figure 6. Transmission $T$ contour plot as function of the phase difference $\theta$ and the energy $\omega$ for different values of $\Delta$ and $\epsilon_{\text{M}}^{\text{u}(d)}$, $\varepsilon_0 = 0$. 

From the above expression, it is evident that this state becomes a BIC in the limit $\epsilon_{\text{M}} = 0$, with a Dirac $\delta$–function in the LDOS of the side coupled QD, with no contribution in transmission. A way to manipulate $\epsilon_{\text{M}}$ is by using a keyboard of locally tunable gates beneath the TSC nanowire [19], where the effective topological wire length, and then the separation between MBSs, can be manipulated by transporting the MBS in the free end of the TSC (for instance $\eta_{\text{M}}^{\text{u}(d)}$) to a position closer/further from the fixed MBS, coupled to the corresponding side QD ($\eta_{\text{M}}^{\text{u}(d)}$). This setup will allow a measurement of the poisoned BICs.
3.2. General phase difference

In order to give a complete analysis of our system, we plot in figure 6 a transmission color map as function of phase difference and energy. The case with $\epsilon^d_M = 0$ is displayed in figures 6(a) and (b), using $\Delta = 0$ and $\Delta = 0.01\Gamma$, respectively. We find that the bound states are completely suppressed around $\omega = 0$, since MBSs interact destructively whenever TSCs are out of phase, i.e. $\theta \neq 2\pi m$, where $m$ is an integer. The discussion above given in section 3.1 can be extended for $\theta = 2\pi m$

On the other hand, figures 6(c), (e) and (g), with $\Delta = 0$, show similar shape around $\omega = 0$, there is no projection of any state in the transmission, regardless the phase difference. However, the behavior changes as we consider $\Delta \neq 0$. In figure 6(d), where only one TSC is within long wire limit ($\epsilon^u_M = 0$), a half-integer transmission is observed at $\omega = 0$, as a consequence of the bound states present in the system, being the BIC covered by the MBS leakage regardless the phase difference $\theta$. The BIC unveiling is achieved regardless $\theta$ whenever both TSCs have non-vanishing inter MBSs coupling ($\epsilon^d_M \neq 0$), as we show in figures 6(f) and (h).

It is important to highlight that the switching for hiding/unveiling a BIC in transmission does not depend on the phase difference between the TSCs and, for fixed $\Delta \neq 0$, can be controlled just by tuning the topological length of TSCs.

4. Summary

In summary, we studied the formation of BICs poisoned by MBSs in a system composed by a triple QD array with side-coupled TSCs nanowires. The BICs developed topological characteristics due to the presence of the MBSs built in the hybrid structure. Asymmetry in QDs energy levels as well as tuning of inter MBSs coupling, driving TSCs from long to short wire limit (or vice versa) using applied gate voltages [19], can control the appearance of BICs poisoned by MBSs. We also have shown that this behavior is not restricted to a specific phase difference between both TSCs. Our findings can be seen as a way to implement protection of the BIC with acquired topological characteristics due to the presence of MBSs in the two following senses: (i) For isolated triple QD structure ($\lambda = 0$), the BIC can be accessed by means of transmission projection whenever $\Delta \neq 0$, then the possibility to write information arises. Implementing a switch that connects a TSC ($\lambda \neq 0$) in long wire limit ($\epsilon^u_M = 0$), the BIC will be covered and the information protected regardless $\Delta$, which means deviations from QDs energy levels. (ii) The switching for fixed $\Delta \neq 0$ can be perform by tuning the wire length to $\epsilon^u_M = 0$ to protect/cover the information and to $\epsilon^u_M \neq 0$ to write/read accessing the information.

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Appendix. Retarded Green’s function

In this appendix we present the method considered in the main text to obtain the system Green’s function. We perform a direct inversion in the form

$$\hat{G}^r(\omega) = [\omega - \hat{H}]^{-1} \equiv \hat{H}^{-1}(\omega)$$

for MBSs,

$$\hat{H}_{\pm 1} = \begin{pmatrix} \omega - \epsilon_{\pm 1} & 0 \\ 0 & \omega + \epsilon_{\pm 1} \end{pmatrix},$$

for lateral QDs and

$$\hat{H}_{0} = \begin{pmatrix} \omega - \epsilon_0 + i\Gamma & 0 \\ 0 & \omega + \epsilon_0 + i\Gamma \end{pmatrix},$$

for the central QD, in which the contribution of the leads is considered. The off-diagonal terms in (A.1) denote the connection between the different elements in the system. The inter QDs coupling matrix is

$$\hat{H}_{0,\pm 1} = \begin{pmatrix} -t & 0 \\ 0 & t \end{pmatrix},$$

while for the QD-MBS coupling

$$\hat{H}_{1(-1),\pm 1} = \hat{H}_{1(1),\pm 1}^\dagger = \begin{pmatrix} \lambda^u_{\pm 1} & \lambda^d_{\pm 1} \\ -\lambda^u_{\pm 1} & -\lambda^d_{\pm 1} \end{pmatrix}.$$
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