

Topological Wireless Power Transfer With Relay Edge States

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Abstract – Using topological edge states of diatomic magnetoinductive waveguides, efficient wireless power transfer in the stopband with superior robustness against disorder is possible. A drawback of this approach is that the evanescent nature of the coupling to the edge states imposes a limit in transfer range. Here, we show that by adding additional interfaces to the waveguides we are able to engineer edge states acting as relays thus overcoming this range limitation.

I. INTRODUCTION

In the study of periodic structures like metamaterials, passband and stopband are familiar concepts: Waves may propagate through the structure in the passband but in the stopband they are unable to. Hence, conventional wisdom has long been that for the purpose of wireless links transmitting power or information, the stopband is of no interest.

However, in the seemingly distant field of condensed matter, the stopband has actually captured attention in recent years. This is because, due to the fundamental topological properties of the bands in some structures, highly robust and strongly resonant modes called topological edge states may exist in the stopband. Counterintuitively and against the aforementioned conventional wisdom, it was shown that these edge states may indeed enable both wireless power transfer [1], [2] as well as communications [3] in the stopband of magnetoinductive lines, sometimes even better than conventional approaches using propagating waves.

One drawback of such topological wireless power transfer has been, that the number of meta-atoms in the line and hence the transfer range was limited by the evanescent nature of the coupling to the edge state. Here, we propose a solution for this issue: We show that, by inserting additional interfaces into the structure, the additional topological edge states excited on these interfaces may restore the performance of the topological wireless link by providing an additional mode as a relay to couple to, and hence allow for longer links to be constructed.

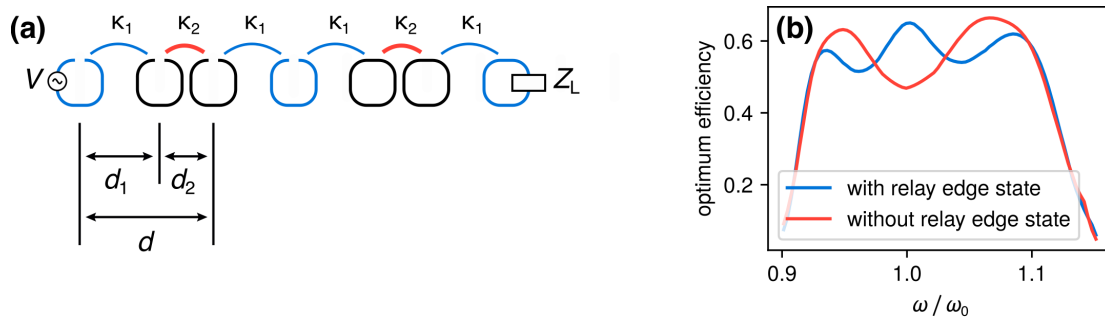


Fig. 1: **(a)** Sketch of a magnetoinductive waveguide with a relay edge state. The elements hosting edge states are coloured blue. The waveguide is formed of meta-atoms with staggered couplings $\kappa_{1,2}$ as well as driven by a voltage source on the first and loaded with a load impedance Z_L on the last element. **(b)** Optimum efficiency for wireless power transfer using a magnetoinductive waveguide with and without a relay edge state. With the relay edge state, the efficient wireless power transfer in the stopband is recovered.

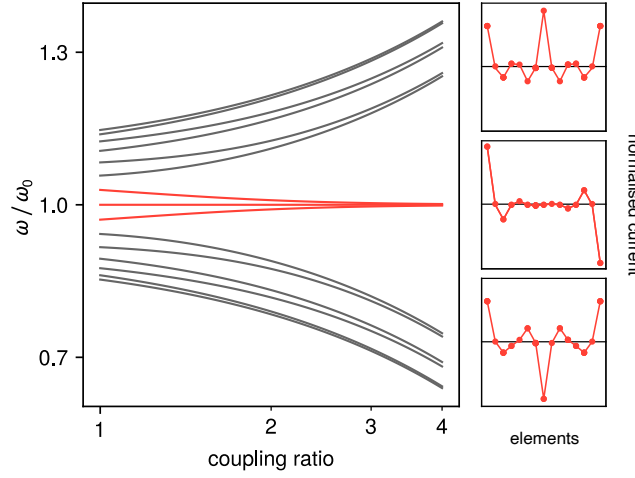


Fig. 2: Eigenmodes of a magnetoinductive waveguide with a relay edge state as a function of the coupling ratio κ_2/κ_1 . To the right, the current profiles corresponding to the states in the stopband (shown as red lines in the left graph) are displayed.

II. TOPOLOGICAL WIRELESS POWER TRANSFER

The model under consideration here is a chain of identical meta-atoms, which is illustrated in Fig. 1(a). Each element is an LCR circuit with a self-impedance of

$$Z_0 = j\omega L + \frac{1}{j\omega C} + R = j\omega L \left(1 - \frac{\omega^2}{\omega_0^2} - j\frac{\omega_0}{\omega Q} \right) \quad (1)$$

where L denotes the self-inductance, C the capacitance, R the resistance, $\omega_0 = 1/\sqrt{LC}$ the resonant frequency, and $Q = \omega_0 L/R$ the quality factor of each resonator. The resonators are coupled by mutual inductances $M_{1,2} = \kappa_{1,2}L/2$, where $\kappa_{1,2}$ are the dimensionless coupling coefficients. We note that the results shown here have been obtained by the theory of magnetoinductive waves [4], in particular by the generalised Kirchhoff's Law, $\mathbf{V} = \mathbf{Z}\mathbf{I}$, where \mathbf{V} and \mathbf{I} are N -dimensional vectors standing for the applied voltages and for the resulting currents (e.g. element I_n of the vector \mathbf{I} denotes the current on the n^{th} element of the array), and \mathbf{Z} is the impedance matrix. From this, a circuit analogon of the Hamiltonian may be calculated to calculate eigenfrequencies as well as eigenmodes [5].

If one takes the conventional diatomic chain with staggered couplings, the resulting two-band circuit model directly maps onto the Su-Schrieffer-Heeger chain, a well-known model which supports topological edge states. This circuit model becomes topologically nontrivial and therefore exhibits edge states for $\kappa_1 < \kappa_2$. These edge states may be coupled evanescently, in a conceptually similar way to the earlier example of the excitation of surface plasmons through a silver slab [6]. This enables wireless power transfer inside the stopband with optimum efficiencies, comparable to those achieved using propagating waves in the passband.

III. RELAY EDGE STATES

We define the efficiency of the wireless power transfer as

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{\frac{1}{2}\text{Re}(Z_L)|I_N|^2}{\frac{1}{2}\text{Re}(I_1 V_1^*)}, \quad (2)$$

where Z_L is the load impedance, V_1 the voltage on the first element, as well as I_1 and I_N the current on the first and last element, respectively. As mentioned above, for a sufficiently small number of elements, the efficiency in

the stopband of a topological chain is comparable to that in the passband. In Fig. 1(b), we show the case of a chain where the length has caused the efficiency (with the load having been optimised to give the optimum efficiency) in the stopband to drop fairly significantly below the efficiency in the passband. As this is due to the evanescent nature of the coupling to the edge state, an additional edge state as a relay should fix this issue. We show in Fig. 1(a) how such a chain looks, with an additional interface placed in the center of the chain. Figure 2 shows the eigenmodes of such a structure (with a higher number of elements to give more pronounced current profiles), where it can clearly be seen that there are edge states inside the stopband localised at both the outer edges as well as at the additional interface. Figure 1(b) clearly shows that this relay edge state recovers the efficiency inside the stopband, which is equal to the passband again due to the added relay edge state despite the increased transfer range.

IV. CONCLUSION

In conclusion, we have shown how relay edge states added may be used to address the range limitations in topological wireless power transfer through magnetoinductive waveguides. This may be of use in mid-range wireless power transfer, where these types of structures are most commonly utilised and the topological approach has shown considerable promise.

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