

# Inductance and capacitance emerging from topological electromagnetism

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Inductors and capacitors are the most essential elements in electronic circuits. They are used for filtering and amplification of electronic signals, which are indispensable in any contemporary electronic devices. The operation principles of commercially used inductors and capacitors are based on classical electromagnetism described by Maxwell's equations. Since they operate with conduction currents in metals, power loss by internal resistance is inevitable. Such a power loss prevents further integration of electronic circuits, which needs to be resolved for the development of information-oriented society.

In this presentation, we report our recent theoretical proposal of the novel inductors and capacitors using topological insulator (TI) heterostructures, with significantly improved power efficiency [1]. TIs show various anomalous responses between electricity and magnetism, such as the anomalous Hall effect and the spin-charge conversion, which are free from power loss by Joule heating. By combining such anomalous magnetoelectric responses with spin dynamics in magnets, we show the emergence of inductance and capacitance in heterostructures of TIs and magnets, with significantly reduced power loss. We build a unified theoretical framework to extract the inductance and capacitance, on the basis of topological quantum field theory [2] describing the anomalous magnetoelectric responses. From this theoretical framework, we numerically evaluate the inductance and capacitance in two-dimensional (2D) and three-dimensional (3D) heterostructures of TI and ferromagnetic insulator (FI). We also compare their power efficiency with the "emergent inductors" reported in previous studies [3-7], which use spin dynamics in metallic magnets to generate inductance, and show that TIs can highly reduce the power loss in inductors.

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[1] Y. Araki and J. Ieda, *J. Phys. Soc. Jpn.* **92**, 074705 (2023).

[2] X.-L. Qi, T. L. Hughes, and S.-C. Zhang, *Phys. Rev. B* **78**, 195424 (2008).

[3] N. Nagaosa, *Jpn. J. Appl. Phys.* **58**, 120909, (2019).

[4] J. Ieda and Y. Yamane, *Phys. Rev. B* **103**, L100402 (2021).

[5] Y. Yamane, S. Fukami, and J. Ieda, *Phys. Rev. Lett.* **128**, 147201 (2022).

[6] T. Yokouchi, F. Kagawa, M. Hirschberger, Y. Otani, N. Nagaosa, and Y. Tokura, *Nature* **586**, 232 (2020).

[7] A. Kitaori, N. Kanazawa, T. Yokouchi, F. Kagawa, N. Nagaosa, and Y. Tokura, *Proc. Nat. Acad. Sci.* **118**, e2105422118 (2021).