Topological Analysis of Non-Symmetric Circuit Laplacians and an Experimental Verification of the Su-Schrieffer-Heeger Topological Circuit

Yang, Russell (School: NUS High School of Mathematics &amp
Science)

The study of topological systems is a very active field. In 2016, the Nobel prize in physics was awarded to the pioneers who studied topological systems such as topological insulators and the Quantum Hall Effect. Topology was developed to study geometric structures where only global properties are of concern. It has since been applied to physical systems with remarkable success; one such area being circuit theory. In this project, Kirchoff's Laws are reformulated so that circuits can be analysed using the powerful tool of topology. The Circuit Laplacian is introduced in this reformulation (analogous to the Hamiltonian in quantum systems). The paradigmatic Su-Schrieffer-Heeger model for topological insulators is used to construct a circuit Laplacian and the corresponding circuit is experimentally recreated. Topological Boundary Resonances in the circuit's edge, analogous to midgap edge states in polyacetylene, are observed. They are protected by the 1-dimensional winding number. Theoretical advancements in the study of non-Hermitian systems are also made. Symmetry breaking in circuit Laplacians is introduced via voltage controlled current sources. The celebrated bulk-boundary correspondence is found to be broken due to non-Hermicity, implying a new state of matter. A large range of degeneracies between the bulk and edge are discovered. These results are attributed to boundary conditions affecting all states in the bandstructure, not just edge states. Topological circuits and non-Hermitian systems establish a connection between electrical engineering and condensed matter physics, where the accessibility, scalability, and operability of electronics synergize with the intricate boundary properties of topological phases; typically not found in traditional quantum systems.

Awards Won:

Third Award of $1,000