Investigation of Two Dimensional Floquet Topological Insulator Using Microwave Network

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The topological insulator is one of the most profound discoveries in theoretical physics during the past few decades. They are "topologically distinct" from conventional insulators for being insulating in the 'bulk' while supporting metallic states on the surfaces. The most extraodinary physical property is the existence of uni-directional transmission along the edge, which is robust to imperfections and has no back-reflection. In 2005, Haldane and Raghu introduced the concept of topological insulator into photonics by theoretically proposing a photonic analogue of the quantum Hall effect in photonic crystals. Wang *et al.* experimentally confirmed this idea by observing uni-directional transmission line in gyromagnetic photonic cystals which operate in the microwave frequency range. "Topological photonics" have also been realized with resonator lattices and waveguide lattice subsequently. However, in all these experiments, edge propagation measurements serves exclusively as the proof of topological nontrivial system due to the lack of direct analog of the Hall conductance or similar linear response-based quantity. During my PhD career, my research has focused on the investigate of two-dimensional Floquet topological insulators using a microwave networks. The first part of my work involves a experimentally measuring a topological edge invariant which consists of the integer winding numbers of scattering matrix eigenvalues in a microwave network. The second part of my study concerns the relation between topological edge invariants and exceptional points by introducing controllable loss and gain into the microwave network.

The network model we used to measure topological edge invariants is two-dimensional network which is mapped into a microwave network using Laughlin's topological pump idea. The experiment setup is a two-port network system with variable phase shifters. By measuring the scattering matrix of the two-port network, we can observe the winding behavior of the eigenvalues. We implemented this experiment using microwave components at 2.5 GHz and sucessfully observed the non-zero winding behavior for non-trivial topological system and zero winding behavior for trivial topological system, as predicted by theoretical arguments but never previously found in an experiment.

Due to the existence of loss, the system we used to measure topological edge invariant is non-Hermitian and actually we can never observe rigorously non-zero winding in a finite system, since there always be a gap in the projected band structure. Moreover, non-Hermitian effects will introduce the novel physical feature of exceptional points into the bandstructure and it is easy to introduce controllable loss and gain into our experiment setup. Hence, we re-implement our experiment setup at 900 MHz and add digital variable attenulators into the system. By controlling gain and loss, we demonstrate, theoretically and experimentally, a direct relationship between a Hermitian topological invariant and exceptional point winding numbers.

In summary, my PhD research has concentrated on investigation of two dimensional floquet topological insulators using microwave network. Two major works have been finished, one is the experimental measurement of topological edge invariants in the form of scattering matrix eigenvalue winding numbers in a microwave network. The other is theoretically and experimentally proving the direct relation between Hermition topological invariant and exceptional point winding numbers.