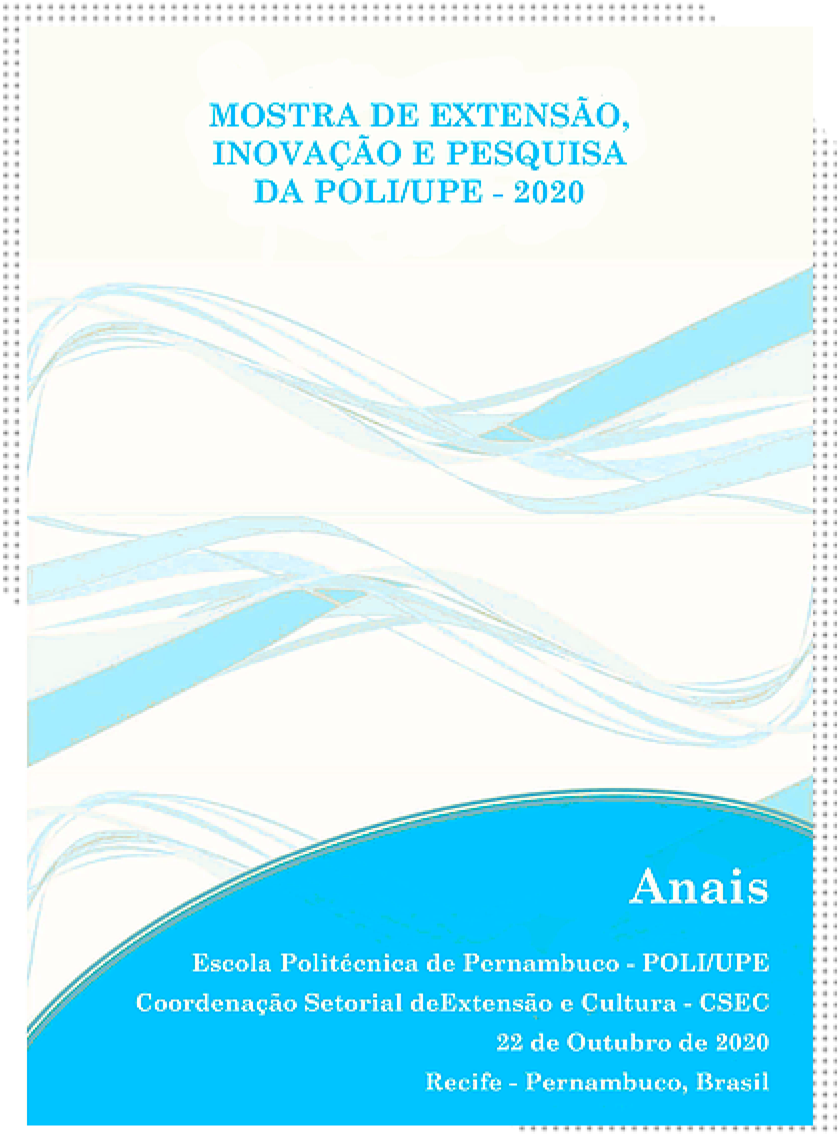
Analytical Approach to Quantum Circuit Theory via Graph Theory



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Summary

In scientific and technological research on nanostructured systems, there are major challenges in understanding the properties of charge, heat and spin transport in electronic systems. The foundations of transport theory in quantum systems involve both aspects of non-equilibrium physics (DE GROOT, 2013) and quantum many-body theory (STEFANUCCI, 2013). Improving the description of low-dimensional systems is still a developing field, even though several aspects of the observed transport have already been clarified. Phenomenological and formalistic aspects involving charge transport, heat, entropy, and spin are one of the main interests for modeling these systems. Mesoscopic physics studies transport phenomena in nanostructures, which can be described by semiclassical techniques (DATTA, 1997). Our line of research deals with the description of observable electronic transport by chaotic quantum dot systems in the form of cumulants of charge transmission statistics for normal reservoirs for Wigner-Dyson symmetry classes (MEHTA, 2004). The methods applied for charge transport in macroscopic systems are adapted to describe electronic transport in mesoscale systems, when quantum aspects must be incorporated. Understanding transport processes at small scales is crucial for identifying accessible degrees of freedom for modeling transport in nanostructures. The electronic current signal verified for a network of quantum dots is characterized as a noise described by the cumulants of the charge count statistics, which reveal transport observables such as conductance and shot noise power. Through a Quantum Circuit Theory (TQC) introduced by Y. Nazarov (NAZAROV, 2009), the cumulants of the charge counting statistics are calculated in the semiclassical regime from a generating function defined by a non-Ohmic pseudocurrent established by a analogous set of "Kirchhof laws" in the form of non-linear algebraic equations. Sena-Junior (SENA-JUNIOR, 2016) showed that quantum-chaotic systems based on semiconductor heterostructures exhibit an anomalous scale theory from the ballistic regime to the diffusive regime, which differs from the usual behavior found in disordered systems, with an emergence of a new universality similar to present spin glass systems. Understanding how the topology and other parameters of the quantum dot network impact the charge transmission process is of natural interest for more efficient modeling for realizing the architecture of these systems obtained by lithography techniques in semiconductor heterostructures. To this end, graph theory provides a more appropriate algebraic approach for describing network structures, such as vehicle traffic on urban roads, data traffic in computer networks, charge transport in electrical circuits, etc. We show a description of TQC for calculating conductance, shot noise power and other higher order cumulants, which provides a description directly in terms of the topology and other parameters of the network. In the semiclassical regime, the conductance of a network of quantum dots presents the same calculation scheme as classical resistive networks. The determination of other higher-order cumulants is also carried out by graph theory. Based on the results, we built an algorithm to implement a program dedicated to calculating cumulants from a given network of quantum dots, which is described by an adjacency matrix weighted by the conductances of the associated graph as input to the code. The construction of the algorithm for calculating cumulants using the Wolfram Mathematica software. The extension of the graph theory approach applied to quantum circuits provides a more efficient systematic method available in the literature for determining the cumulants of charge transmission statistics in quantum dot networks in the semiclassical regime and, above all, for determining their quantum corrections. directly in terms of the corresponding graph structure. This approach will allow the investigation in future work of so-called inverse problems, that is, from a set of values for the cumulants to determine the algebraic structure of the corresponding graph, allowing the designation of the topology based on the load transmission profile of interest. Carrying out this approach on normal reservoirs will allow future investigation on normal-superconducting reservoirs. mainly for determining their quantum corrections directly in terms of the structure of the

corresponding graph. This approach will allow the investigation in future work of so-called inverse problems, that is, from a set of values for the cumulants to determine the algebraic structure of the corresponding graph, allowing the designation of the topology based on the load transmission profile of interest. Carrying out this approach on normal reservoirs will allow future investigation on normal-superconducting reservoirs. mainly for determining their quantum corrections directly in terms of the structure of the corresponding graph. This approach will allow the investigation in future work of so-called inverse problems, that is, from a set of values for the cumulants to determine the algebraic structure of the corresponding graph, allowing the designation of the topology based on the load transmission profile of interest. Carrying out this approach on normal reservoirs will allow future investigation on normal-superconducting reservoirs.

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