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Quantum Graph Approach for Energy and Information Transfer through Networks of Cables

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Abstract : High-frequency cables commonly connect modern devices and sensors. Interestingly, the proportion of electric components is rising fast in an attempt to achieve lighter and greener devices. Modelling the propagation of signals through these cable networks in the presence of parameter uncertainty is a daunting task. In this work, we study the response of high-frequency cable networks using both Transmission Line and Quantum Graph (QG) theories. We have successfully compared the two theories in terms of reflection spectra using measurements on real, lossy cables. We have derived a generalisation of the vertex scattering matrix to include non-uniform networks – networks of cables with different characteristic impedances and propagation constants. The QG model implicitly takes into account the pseudo-chaotic behavior, at the vertices, of the propagating electric signal. We have successfully compared the asymptotic growth of eigenvalues of the Laplacian with the predictions of Weyl law. We investigate the nearest-neighbour level-spacing distribution of the resonances and compare our results with the predictions of Random Matrix Theory (RMT). To achieve this, we will compare our graphs with the generalisation of Wigner distribution for open systems. The problem of scattering from networks of cables can also provide an analogue model for wireless communication in highly reverberant environments. In this context, we provide a preliminary analysis of the statistics of communication capacity for communication across cable networks, whose eventual aim is to enable detailed laboratory testing of information transfer rates using software defined radio. We specialise this analysis in particular for the case of MIMO (Multiple-Input Multiple-Output) protocols. We have successfully validated our QG model with both TL model and laboratory measurements. The growth of Eigenvalues compares well with Weyl's law and the level-spacing distribution agrees so well RMT predictions. The results we achieved in the MIMO application compares favourably with the prediction of a parallel on-going research (sponsored by NEMF21.)

Keywords : eigenvalues, multiple-input multiple-output, quantum graph, random matrix theory, transmission line
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