Final report for ESF Short Visit Grant

"Accurate modelling of high Q-resonators and scatterers with rotational symmetry"

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The visit was planned for the interval 23 October till 26 the October 2012. However due to the fog at Vienna airport my flight was delayed to 24th October which resulted in a two day meeting.

During my visit Prof A. Nosich and I discussed recent developments in research area outlined in the proposal, most notably around the Body of Revolution method application to the 3D optical resonator modeling.
On 24 October, I was introduced to the on-going research of the students and post-doctoral researchers of the host laboratory. This was useful for determining the most promising topics for a future collaboration.
On 25 October, I was invited to attend a Mykhaylo Balaban PhD Viva and act as an overseas reporter for his PhD thesis entitled "Method of Analytical Regularisation in the Problem of Electromagnetic Wave Scattering by a Thin Dielectric disc". As far as I know, Balaban's work was done, in part, when he had been on an ESF-Newfocus Exchange Travel Grant visit to the University of Rennes 1, France. Earlier he had also stayed at the University of Nottingham due to the joint projects funded by the Royal Society where I could observe his progress and discuss the developments.
One of the topics studied by Balaban, the scattering by a resistive disk, can be extended to the scattering of THz range waves by the disks made of graphene. This can be a subject of a future ESF-Newfocus Exchange Travel Grant at the University of Nottingham.

My report on this PhD thesis is attached in this document.

Report on the PhD thesis "Method of analytical regularization in the problem of electromagnetic wave scattering by a thin dielectric disk" by Mykhaylo V. Balaban

The thesis presents an efficient analytical tool based on integral equations for analysis of scattering and absorption of electromagnetic waves by a thin dielectric disk.
Focus on scattering from a dielectric disk is very timely as thin dielectric disks play important role in both microwave and photonic applications as resonators, printed and dielectric disk antennas, lasers and biosensors. To develop a numerical tool that can analyse scattering from thin 3D disks with guaranteed accuracy and convergence is not a trivial task and is practically highly relevant.
A novel and in-depth theoretical approach is presented where the two-side generalized boundary condition on the disk median together with the radiation condition and edge currents condition are combined with Maxwell equations to give dual integral equations. Method of analytical regularization is then applied to reduce dual integral equations to integral equations of Fredholm second kind. The integral equations are then numerically solved using Nystrom method and Gaussian quadratures.

The thesis is organized as follows:
Chapter 1 gives literature overview of different analytical approaches and approximations used for analysis of thin disks and outlines general approach to analytical regularization, dual integral equations, generalized boundary conditions and Nystrom method.
Chapter 2 gives a more detailed theoretical account on wave scattering by thin dielectric and resistive disc together with the zero-thickness PEC disc. Analytical regularization scheme is also presented so that dual integral equations are reduced to Fredholm second kind IEs.
Chapter 3 gives expressions for several different types of incident electromagnetic field in the Fourier-Bessel space. Variety of sources have been derived ranging from plane wave sources to full 3D sources and these include: plane TE and TM waves, horizontal and vertical electric and magnetic dipoles on the disk axis, arbitrary oriented off-axis dipoles, field of electric and magnetic ring currents and complex Huygens element.
Chapter 4 analyses radiation of localized sources in the presence of a zero-thickness PEC and resistive disks. In both cases the Nystrom method using Gauss quadratures is used and a detailed numerical analysis of accuracy (or errors of truncation of integration interval and discretisation) is presented and shown a stable algorithm where the truncation error decreases as both truncation parameter and discretisation order are increased. The Chapter also investigated radiated powers and far field radiation patterns for horizontal and magnetic dipoles and complex Hygens element in vicinity of PEC disc as well as radiation pattern of electric ring current in vicinity of a resistive disk.

Chapter 5 presents theoretical aspects of a horizontal dipole positioned on and off the z-axis and radiating in the presence of thin dielectric disc. The radiated and absorbed powers are computed and it is shown that they exhibit peaks near natural frequencies of whispering gallery modes of a thin disc resonator. It is shown that position of the dipole has significant impact on what type of modes are excited in the dielectric disk.
Chapter 6 outlines the main conclusion of the thesis.
This work presents original contribution in the area of electromagnetic theory for analysis of scattering of fields in the presence of thin dielectric disks. Key advances that I appreciate the most are:

- the use of Maxwell equations with generalized boundary conditions, radiation condition and currents conditions on the edge of the disk to correctly describe the behavior of the fields in the vicinity of thin disks.

- Summary of explicit equations for a variety of field sources in the spectral domain including electric and magnetic dipoles, rings of electric and magnetic current rings and complex dipoles and Huygens element.

- Detailed study of scattering of real and complex dipoles in the presence of the thin dielectric disks and results for radiated and absorbed power obtained. The method shows that by positioning the dipole a controlled set of modes with fixed radial or azimuthal order can be excited. The thesis demonstrates the immediate application of this for quantification of Purcell effect that is highly relevant for modelling single photon sources for quantum cryptography. The method is also a very powerful tool in obtaining radiation patterns and compares extremely well with numerical FECO program.

I would like to summarize that this is an original contribution to the very topical area of scattering by thin disk resonators and that results obtained are very valuable to scientific community. The thesis is very impressive and is presented on a high standard, well organized and the theoretical approach is presented logically and clearly. The work presented involved theoretical derivations, development of efficient computational algorithm and computation and interpretation of results. The work has been widely presented on esteemed conferences and international journals. This is therefore a work worthy of a Doctor of Philosophy degree.