Analysis of Transient Electromagnetic Wave Interactions on Graphene-Based Devices using Integral Equations

Yifei Shi* [(1)], Ismail E. Uysal[(1)], Ping Li[(1)], H. Arda Ulku[(1, 2)], and Hakan Bagci[(1)]
(1) Division of Computer, Electrical, and Mathematical Sciences and Engineering
King Abdullah University of Science and Technology (KAUST)
Thuwal, Saudi Arabia
(2) Department of Electronics Engineering
Gebze Institute of Technology, Kocaeli, Turkey

Graphene is a monolayer of carbon atoms structured in the form of a honeycomb lattice. Recent experimental studies have revealed that it can support surface plasmons at Terahertz frequencies thanks to its dispersive conductivity. Additionally, characteristics of these plasmons can be dynamically adjusted via electrostatic gating of the graphene sheet (K. S. Novoselov, et al., Science, 306, 666-669, 2004). These properties suggest that graphene can be a building block for novel electromagnetic and photonic devices for applications in the fields of photovoltaics, bio-chemical sensing, all-optical computing, and flexible electronics. Simulation of electromagnetic interactions on graphene-based devices is not an easy task. The thickness of the graphene sheet is orders of magnitude smaller than any other geometrical dimension of the device. Consequently, discretization of such a device leads to significantly large number of unknowns and/or ill-conditioned matrix systems.

To circumvent this bottleneck, in this work, an integral equation based approach is adopted. The proposed approach enforces the time domain resistive boundary condition (TD-RBC) (Q. Chen, et al., Microw. Opt. Technol. Lett., 42, 213-220, 2004) on the graphene sheet and the time domain Poggio-Miller-Chang-Harrington-Wu-Tsai surface integral equation (PMCHWT-SIE) (B. Shanker, et al., IEEE Trans. Antennas Propag., 57, 1506-1520, 2009) on the surfaces of the dielectric volumes constituting the device. This approach calls for introducing electric and magnetic equivalent current densities on both sides of a given surface. For dielectric-only surfaces there is only a sign difference between both sets of currents. When a graphene sheet coincides with a dielectric surface, the same applies for the magnetic current sets, but the relation between electric currents on both sides of the common surface is governed by the TD-RBC.

Unknown currents are expanded using Rao-Wilton-Glisson (RWG) basis functions in space and shifted Lagrange interpolators in time. Inserting this expansion into the coupled equations of TD-RBC and PMCHWT, and Galerkin testing the resulting equations at discrete times yield a system of equations. This system is solved for the unknown current expansion coefficients using a marching on-in-time (MOT) scheme. The MOT scheme requires time samples of graphene's surface resistivity to be computed (V. Nayyeri, et al., IEEE Trans. Antennas Propag., 61, 6107-6114, 2013). This is carried out using a fast relaxed vector fitting (FRVF) algorithm applied to the frequency samples of the dispersive resistivity (B. Gustavsen and A. Semlyen, IEEE Trans. Power Del., 14, 1052–1061, 1999). Numerical results, which demonstrate the applicability of the proposed MOT solver to the analysis of transient electromagnetic interactions on graphene-based devices, will be presented.