FDTD Modeling of Graphene-Based RF Devices: Fundamental Aspects and Applications

Xue Yu and Costas D. Sarris
The Edward S. Rogers Sr. Department of Electrical and Computer Engineering
University of Toronto, Toronto, ON, Canada

Since the fabrication of graphene in 2004 (K.S. Novoselov et al, Science, 306, 5696, 666-669, 2004), several applications in the domain of radio-frequency (RF) nanoelectronics have been actively investigated. In addition to graphene based FETs (P. Russer and N. Fichtner, Microwave Magazine, 11, 2010) and waveguides (G. W. Hanson, J. App. Phy., 104, 084314, 2008), the potential of graphene as a platform for two-dimensional meta-materials has been recently indicated (A. Vakil, and N. Engheta, Science, 332, 6035, 1291-1294, 2011). To that end, the controllability of graphene’s conductivity via its chemical potential (which can also be controlled by an external bias voltage) has been harnessed.

Along with the intensive research interest in RF nanotechnology, a need for reliable and efficient modeling techniques has emerged. Established electromagnetic modeling tools, such as the Transmission-Line Matrix (TLM) (L. Pierantoni, et al, 2011 IEEE MTT-S Int. Microwave Symp. Dig., 2011) and the Finite-Difference Time-Domain (FDTD) methods (G. D. Bouzianas, et al, General Assembly and Sci. Symp., 2011 XXXth URSI, 2011) have been employed. However, these methods are inherently limited by the fact that ultra-thin graphene layers impose severe restrictions on the cell size and time step.

We consider these limitations from a fundamental point of view, through a numerical stability and dispersion analysis for standard and higher-order FDTD schemes. Moreover, a thorough investigation of the PML performance as a function of the chemical potential and frequency is performed and optimal parameters are extracted. Following Bouzianas et al, we consider sub-cell FDTD (M. Karkkainen, IEEE Trans. Microwave Theory Tech., 51, 1774-1780, 2003) and enable its application to practical problems, by formulating a sub-cell perfectly matched layer (PML) absorber, which terminates composite Yee cells that include thin graphene layers.

With a full-wave solver in place, several applications of interest are investigated, with emphasis on conventional guided wave structures, such as coupled microstrip lines and slotlines, as well as sub-wavelength focusing screens and hyperbolic metamaterials.