Circuit Modeling of AC Performance of Graphene Nanodevices

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We present here our rigorous modelling and quantitative predictions of the ac performance of graphene-nanoribbon (GNR)-based devices and components, including interconnects, antennas, transistors, metasurface and metamaterials. We focus first on microwave, millimeter-wave and terahertz (THz) electronic devices. We propose a physics-driven circuit model, which includes quantum effects in a semi-classical distributed-element transmission-line model, in order to efficiently study the electromagnetic properties and energy transport of quasi-monochromatic fields along the channel formed by an isolated GNR and the conducting ground plane. This circuit model considers the classical magnetic inductance and electrostatic capacitance of the line, as well as its kinetic inductance and quantum capacitance, thus providing the propagation constant and characteristic impedance of complex transmission-line circuits based on GNR. This high-frequency circuit model is of paramount importance for a correct modelling of on-chip signal propagation and radiation in next-generation, ultra-scaled VLSI designs and communications.

In addition, we propose the design and circuit model of metamaterials composed of periodic arrays of deeply subwavelength, locally-gated GNRs pitched on top of a grounded dielectric slab. This metamaterial may realize interesting effects, including a “metaferrite” response with desired magnetic properties at few THz. These electromagnetic properties, not available in nature, but physically realizable with metamaterials and nanotechnology, may pave the way to new concepts in THz electronics. In addition, thanks to the tunability of Fermi energy (or work function) of graphene, we are able to tune in real time the effective permeability of these GNR-metamaterials, from positive to near-zero and negative values. We pay particular attention to the use of a simple circuit model to predict the performance and effective permeability of GNR-metamaterials, as a function of the bias voltage. Finally, we demonstrate that a thin GNR-metamaterial over a conducting ground plane may unlock enormous potentials for electronically-controlled, tunable and switchable THz and far-infrared applications, including artificial magnetic effects, perfect magnetic conductors, and Salisbury absorbing screens.