Linear and Non-Linear Electromagnetic Scattering from Carbon Nanotubes with Complex Shapes

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The electromagnetic scattering characteristics of carbon nanotubes (CNT) have been extensively studied in recent decades fueled by advances in fabrication techniques, computational modeling, three-dimensional (3D) X-ray tomography, and electromagnetic metrology. Recently, advanced fabrication techniques have been developed to allow the controlled growth of one or more junctions, off the main CNT, forming unique Y-shaped and K-shaped carbon nanostructures. The angle at each junction and the properties of each branch can be varied by the careful control of the fabrication conditions. The conductivity of these nanostructures is not uniform and the junctions can show non-linear behavior due to quantum effects. In this work, we calculate the electromagnetic scattering characteristics of carbon nanotubes with complex shapes accounting for any non-linear effects that can occur at the junction locations. Moreover, we also quantify the electromagnetic response of these complex carbon nanostructures using Characteristic Mode Analysis (CMA). CMA decomposes the current flowing through a scatterer in terms of a set of fundamental modes and it provides the relative significance of each at a certain frequency. By studying the differences in mode behavior, we will use CMA to explain how the electromagnetic response of complex carbon nanostructures, such a Y-shaped and K-shaped nanostructures, differ from that of pristine straight CNTs. Furthermore, we will show how the electromagnetic response and the modal behavior of these complex carbon nanostructures vary with the angle of the junction and the chirality of each branch. These results will pave the way for using these complex CNT nanostructures in nanoelectronics, smart composites, and in plasmonic sensor applications.