Theory of Characteristic Modes for Electromagnetic Scattering of Single-Walled Carbon Nanotubes with Realistic Shapes

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The Theory of Characteristic Modes (TCM) has been used to analyze and design antennas of various shapes. In this work, we present a novel application of the TCM in quantifying the terahertz resonances in the electromagnetic spectrum of worm-like metallic Single-Walled Carbon Nanotubes (SWCNT) with realistic shapes. The Theory of Characteristic Modes identified significant differences between the characteristic modes of SWCNTs and the characteristic modes of perfectly conducting (PEC) wires with the same shapes and dimensions. The first difference is that the axial current of CNTs can be expressed, at resonance frequencies, in terms of a single mode whereas multiple modes can contribute to the resonances of PEC structures. The second difference is that the characteristic currents are sinusoidal at resonance frequencies, for a wide variety of SWCNT shapes, as long as the bending curvature of the SWCNTs is not extremely large. The third difference is that the TCM normalization factor in the TCM expansion of the SWCNT current varies weakly with the shape of the SWCNT, depending primarily on the distributed resistance and the contour length of the SWCNT. Finally, SWCNTs resonate at wavelengths that are much larger than their contour lengths and, therefore, the phase variations of the incident electric field can be neglected in the calculation of the Modal Excitation Coefficients in the TCM expansion. Using these differences, we have developed approximate formulations that directly link the SWCNT shape with the peak amplitudes of the resonances. We will show that these formulations are valid for a wide variety of SWCNT lengths and shapes. These formulations can be used, as the first step, in establishing the use of electromagnetic waves for the nondestructive evaluation of SWCNT shapes.