Recent Progress on Unstructured-Mesh Electromagnetic Particle-in-Cell Algorithms for Kinetic Plasma Simulations based on Discrete Exterior Calculus

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We summarize recent progress on electromagnetic particle-in-cell (PIC) algorithms for fully kinetic plasma simulations with exact charge-conservation properties on general unstructured finite-element meshes. Charge conservation is derived from first principles by adopting the exterior calculus of differential forms to represent field, currents, and charges as differential forms of various degrees. This choice provides precise rules for the localization of the degrees of freedom of the Maxwell-Vlasov system on appropriate mesh elements (nodes, edges, facets, volumes). Charge conservation is obtained without the need for any correction schemes. Whitney forms are used as interpolants from discrete differential forms back to continuum space, and to derive Hodge star operators which incorporate all metric information. The field update is based on the first-order coupled Maxwell's curl equations to suppress spurious modes with secular growth otherwise present in the solution space of the second-order vector wave equation. We provide several numerical examples to simulate high-power microwave amplifiers designed to harness bunching effects from Cherenkov radiation, to compute dispersion diagrams of electron Bernstein waves, and to analyze multipactor effects in RF devices, and analyze numerical Cherenkov radiation from PIC simulations of plasma beams in the relativistic regime.