Two Emerging Multiphysics FDTD Applications from the Megameter Scale at 3 Hz to the Nanometer Scale at 300 THz

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We foresee that, as computer and algorithm capabilities expand, finite-difference time-domain (FDTD) modeling will often be performed in the context of multiphysics simulations involving the simultaneous solution of the Maxwell's equations of classical electrodynamics and other fundamental equations of physics. Two examples of such multiphysics problems will be discussed in this paper. These examples "book-end" the spectrum from the megameter scale at ~3 Hz to the nanometer scale at ~300 THz.

- Example 1: Coupling of the Earth's seismic activities to its global electromagnetic environment at extremely low frequencies (ELF).

  Three-dimensional (3-D) finite-element models of the mechanics of plate tectonics, deformation, and fracturing will provide data for subterranean current sources due to piezoelectric and related effects which transduce changes in rock stresses to time-dependent electric signals. FDTD will then be applied to model the generation and propagation of electromagnetic waves due to these sources. 3-D FDTD models will account for the inhomogeneous dielectric properties of the entire global Earth-ionosphere waveguide system, including the lithosphere, oceans, and ionosphere within at least ±100 km of the Earth's surface. The end result of such modeling may be means to anticipate large-scale seismic events, if unique precursory signatures can be detected above the natural ELF noise background.

- Example 2: Coupling of the quantum behavior of electrons in multi-level atomic systems to photonic feedback systems.

  Systems of equations that describe electron populations within, and transitions between, multiple energy levels in atomic systems will be coupled to 3-D FDTD models of electromagnetic wave propagation within deterministic and random photonic feedback structures containing the atoms. There is emerging evidence that random arrangements of such atoms can yield lasing behavior at thresholds about as low as for deterministic arrangements, but with much lower manufacturing costs. More broadly, the synthesis of classical and quantum computational electrodynamics will assist in the development of a variety of 21st-century electronic and photonic devices engineered at the nanometer scale.

We expect that these and similar multiphysics FDTD applications will yield significant benefits for our society in areas as diverse as computing, telecommunications, and public health and safety.