To be presented at Applied Computational Electromagnetics Society (ACES) – 2021, 1-5 Aug.
https://aces-society.org/conference/Online-Live_2021/

Paper Number: ACES2021OL-1289

Nonstandard Finite Difference Time Domain Methodology for Harmonics Generation in Nonlinear Dielectrics

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Abstract: Nonstandard (NS) finite difference time domain (FDTD) methodologies have been developed to solve Maxwell's equations with high accuracy on a coarse grid [1]. In this paper we extend the NS-FDTD methodology to nonlinear optics. As an example we simulate second harmonic generation and compare with theory.

In units in which $\varepsilon_0 = 1$, $\varepsilon = 1 + \chi^{(1)}$, then $\mathbf{D} = \varepsilon\mathbf{E} + \mathbf{P}^{\mathrm{NL}}$, $\mathbf{P}^{\mathrm{NL}}$ = nonlinear polarization.

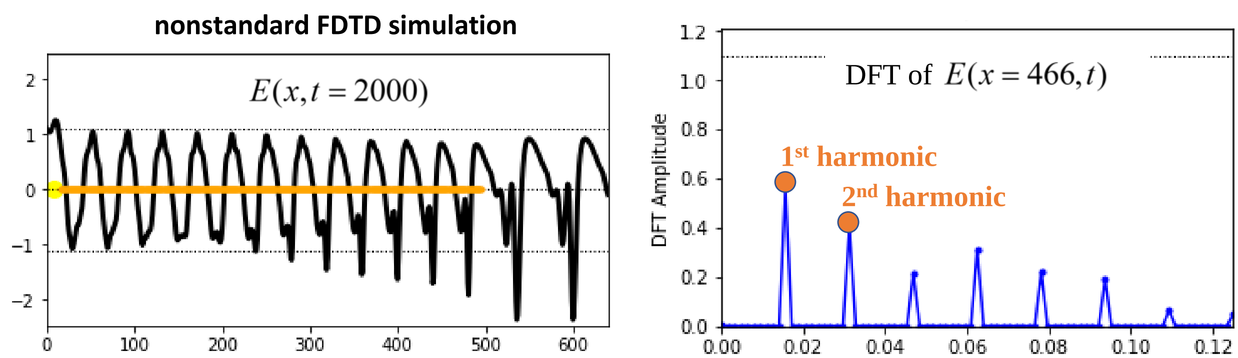
Taking $\mu = \text{constant} = \mu_0 = 1/c^2$ and $\nabla \cdot \mathbf{E} = 0$, Maxwell's equations reduce to

source turns on at t = 0

one dimension

$$\left(\partial_t^2 - \frac{c^2}{\varepsilon}\nabla^2\right)\mathbf{E} = -\frac{1}{\varepsilon}\partial_t^2\mathbf{P}^{\mathrm{NL}}, \quad P^{\mathrm{NL}} = \chi^{(2)}E^2 \;\rightarrow\; \left(\partial_t^2 - \frac{c^2}{\varepsilon}\partial_x^2\right)E(x,t) = -\frac{\chi^{(2)}}{\varepsilon}\partial_t^2 E(x,t)^2 + s(t)\,.$$

The ordinary FDTD algorithm is numerically unstable. We have devised on based on a nonstandard finite difference model that is stable and accurate on a coarse numerical grid.



(Left) Source (yellow dot) generates an electromagnetic field in free space, which propagates into a nonlinear dielectric material (orange). The amplitude of the second harmonic and sum frequency amplitudes grow as the field propagates through the material. (**Right**) Discrete Fourier transform of the field.

We have extended this methodology to the 2- and 3-dimensions and to the full form of Maxwell's equations, and incorporated higher (than 2nd) order polarizations.

Reference:

[1] J. B. Cole and S. Banerjee, Computing the Flow of Light. SPIE Press, 2017.
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