Material Plugins

Practical Implementation Demo
Part 2: Two level system

DECEMBER, 2014

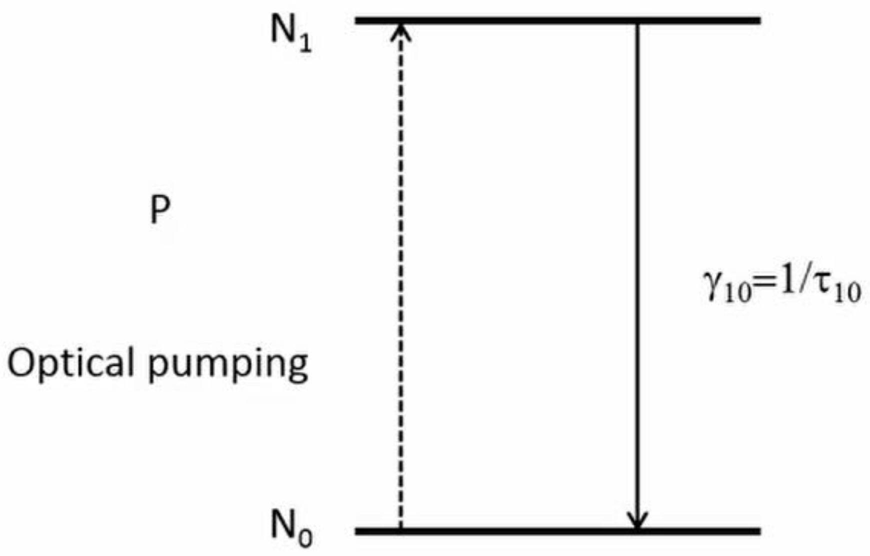
Outline

The 2 level model

Practical implementation and testing on Windows

Two level system example

We'll follow the model of Taflove for a 4 level system but reduce it to 2 levels



References:

- Chang and Taflove, Optics Express, 2004, 3827-3833.
- Taflove, Computational Electromagnetics: The Finite-Difference Time-Domain Method. Boston: Artech House, (2005).

Two level system example

Equations

$$\omega_0^2 \vec{P}(t) + \gamma P^{'}(t) + P^{''}(t) = \zeta (N_1 - N_0)\vec{E}(t)$$

$$\vec{P} = \frac{\vec{P}_{SI}}{\varepsilon_0}$$

$$\frac{dN_1}{dt} = -\gamma_{10} N_1 + \frac{\varepsilon_0}{\hbar\omega}\vec{E}\cdot\frac{d\vec{P}}{dt}$$

$$\frac{dN_0}{dt} = +\gamma_{10} N_1 - \frac{\varepsilon_0}{\hbar\omega}\vec{E}\cdot\frac{d\vec{P}}{dt} = -\frac{dN_1}{dt}$$

We ignore the additional terms from PEP that Taflove introduced

The level populations are normalized to the electron density

Two level system example

It looks like the Lorentz model but except for N_0-N_1 and $\gamma=2\delta$

$$\omega_0^2 \vec{P}(t) + \gamma P'(t) + P''(t) = \zeta N_d \boxed{(N_0 - N_1)} \vec{E}(t) \qquad \zeta = 6\pi c^3 \gamma_{10} / \omega_0^2$$

To update we use

$$\vec{P}^{n+1} = a_1 \vec{P}^n + a_2 \vec{P}^{n-1} + a_3 (N_1 - N_0) \vec{E}^n$$

$$a_1 = \frac{2 - \Delta t^2 \omega_0^2}{0.5\gamma\Delta t + 1}$$

$$a_2 = \frac{0.5\gamma\Delta t - 1}{0.5\gamma\Delta t + 1}$$

$$a_3 = \frac{\zeta N_d \Delta t^2}{0.5\gamma\Delta t + 1}$$

暂停

Two level system example

Then we have to solve the rate equations

$$\frac{N_1^{n+1} - N_1^{n-1}}{2\Delta t} = -\gamma_{10} N_1^n + \frac{\varepsilon_0}{N_d \hbar \omega} \vec{E}^n \cdot \frac{\vec{P}^{n+1} - \vec{P}^{n-1}}{2\Delta t}$$

$$N_1^{n+1} = -2\Delta t \gamma_{10} N_1^n + N_1^{n-1} + \frac{\varepsilon_0}{N_d \hbar \omega} \vec{E}^n (\vec{P}^{n+1} - \vec{P}^{n-1})$$

$$N_1^{n+1} = b_1 N_1^n + N_1^{n-1} + b_2 \vec{E}^n (\vec{P}^{n+1} - \vec{P}^{n-1})$$

$$N_0^{n+1} = 1 - N_1^{n+1}$$

$$b_1 = -2\Delta t \gamma_{10}$$

$$b_2 = \frac{\varepsilon_0}{N_d \hbar \omega_0}$$

Demonstration of implementation

We need a material with 4 Parameters

- $\omega_0, \gamma, \gamma_{10}$, N_d

We need to store P^n and P^{n-1} and $N_1{}^n$ and $N_1{}^{n-1}$ (4 storage fields)

We need 5 constants per axis (a_1, a_2, a_3, b_1, b_2)

We need to update all 3 axes (P_x, P_y and P_z)

Demonstration

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illuminating the way