Learning Tidy3D

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Lecture Outline

- Introduction to Tidy3D

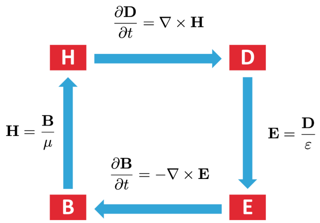
Introduction

FDTD method allows you to compute the evolution of electromagnetic field in the *time domain*.

Given some device $\epsilon(\vec{r})$ and an incident field or current source $\vec{J}(\vec{r}, t)$, internally, FDTD solves these maxwell's equations:

$$\nabla \times \vec{E}(\vec{r}, t) = -\mu_0 \frac{\vec{H}(\vec{r}, t)}{dt} \tag{1}$$

$$\nabla \times \vec{H}(\vec{r}, t) = \epsilon(\vec{r})\epsilon_0 \frac{d\vec{E}(\vec{r}, t)}{dt} + \vec{J}(\vec{r}, t) \tag{2}$$



Field Update

The diagram is from Simulation Documentation

Starting Tidy3D

These software packages should be imported everytime you start a tidy3D project:

```python
import tidy3d as td # Main package
import tidy3d.web as web # Used to run the simulation
import matplotlib.pyplot as plt # Used for plotting results
import numpy as np # Used for numerical calculations
```

Before Simulation

Before the simulation, we have to define some key parameters of the electromagnetic waves that we will use across the simulation:

```
lambda_range = (1.1, 1.6)    # wavelength range (μm)
freqs = (td.C_0 / lambda_range[1], td.C_0 / lambda_range[0])  # frequency range
freq0 = np.mean(freqs)       # center frequency
lda0 = td.C_0 / freq0        # center wavelength
bandwidth = 0.38             # normalized bandwidth
freqw = bandwidth * (freqs[1] - freqs[0])  # bandwidth in Hz
```

Note: All numbers in tidy3d are in **microns** (μm)

Basic Workflow

Here's how to simulate something:

```python
# Defining a simulation
simulation1 = td.Simulation(
    # inputs
)
```

The 7 required inputs are:

- Computational Domain Size
- Grid Specifications (Discretization size)
- Structures
- Sources
- Monitors
- Run time
- Boundary Condition Specification

We will introduce these 7 parameters by simulating a huygen's

Running a Simulation

The most basic way of running the simulation is using the *web* object we imported from tidy3d:

```
# Running a simulation
sim1_data = web.run(simulation1, task_name='any-unique-name', path='data/descriptive-name.
```

Simulation data is stored as an HDF5 file at the **file path** you specify.

1 Computational Domain Size

Size in x, y, and z directions.

```
p = 0.666 #nm → Periodicity
Lx, Ly, Lz = p, p, 2 * lda0
sim_size = [Lx, Ly, Lz]

# Defining a simulation
simulation1 = td.Simulation(
    # A square computational domain
    size = sim_size
)
```

2 Grid Specifications

Specifications for the simulation grid along each of the three directions.

```
# Define Grid size
spec = td.GridSpec.auto(min_steps_per_wvl=40, wavelength=lda0)

# Defining a simulation
simulation1 = td.Simulation(
    # A square computational domain
    size = (x, y, z),
    grid_spec=spec,

)
```

- Typically, the size of a unit cell is $\frac{\lambda}{20}$

td.GridSpec contains many functions to help define the grid, the most commonly used are:

```python
td.GridSpec.uniform(dl=grid_size)
td.GridSpec.auto(min_steps_per_wvl=40, wavelength=lda0)
```

- **uniform** - Use the same Uniform 1D grid along each of the three directions.
  - **dl** (float) – Grid size for uniform grid generation.
- **auto** - Use the same non-uniform grid along each of the three directions.
  - **min_steps_per_wvl**(ConstrainedFloatValue = 10.0) – Minimal number of steps per wavelength in each medium.
  - **wavelength** (float) – Wavelength to use for the step size and for dispersive media epsilon.

3 Structures

td.Structure is the meat of the simulation. It defines a physical object that interacts with the electromagnetic fields. The `structures` field is a list of `Structure` objects that you create.

```
# set up simulation
sim = td.Simulation(
    size=sim_size,
    grid_spec=spec,
    structures=[superstrate, substrate, cylinder],
```

```python
# set up simulation
td.Structure(
    # inputs
)
```

A structure needs two inputs at least: - **geometry** (td.Box, td.Cylinder, td.Sphere, td.TriangleMesh (STL file), etc.) - **medium** Mediums define the optical properties of the materials within the simulation.
(e.g. td.Medium)

According to the paper on huygen’s metasurface, I defined these four structures:

```python
t = 2  # thickness of the substrate # THIS SHOULD BE CHANGED TO INFINITE
substrate = td.Structure(
    geometry=td.Box(
        center=(0,0,-t/2),
        size=(td.inf,td.inf,t)
    ),
    medium=td.Medium(permittivity=1.45**2, name='oxide'),
    name='substrate'
)

superstrate = td.Structure(
    geometry=td.Box(
        center=(0,0,t/2),
        size=(td.inf,td.inf,t)
    ),
    medium=td.Medium(permittivity=1.4**2, name='glass'),
    name='superstrate'
)

polymer = td.Structure(
    geometry=td.Box(
        center=(0,0,0),
        size=(td.inf,td.inf,2*t)
    ),
    medium=td.Medium(permittivity=1.66**2, name='polymer'),
    name='polymer'
)
```

4 Sources

A source specifies the input.

5 Monitors

6 Run time

7 Boundary Condition Specification

Bonus: Symmetry

Symmetry can be used to greatly reduce the computational cost –>