

Learning Tidy3D

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Lecture Outline

- Introduction to Tidy3D

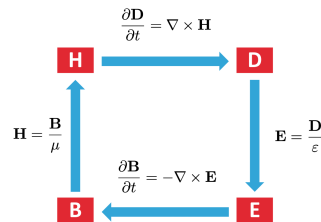
Introduction

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:

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

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



Field Update



The diagram is from [Simulation Documentation](#)

Starting Tidy3D

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

```
1 import tidy3d as td # Main package  
2 import tidy3d.web as web # Used to run the simulation  
3 import matplotlib.pyplot as plt # Used for plotting results  
4 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:

```
1 lambda_range = (1.1, 1.6)    # wavelength range ( $\mu m$ )
2 freqs = (td.C_0 / lambda_range[1], td.C_0 / lambda_range[0]) # frequency range
3 freq0 = np.mean(freqs)       # center frequency
4 lda0 = td.C_0 / freq0        # center wavelength
5 bandwidth = 0.38             # normalized bandwidth
6 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:

```
1 # Defining a simulation
2 simulation1 = td.Simulation(
3     # inputs
4 )
```

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

```
1 # Running a simulation
2 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.

Simulation Inputs

The 7 required inputs are:

1. Computational Domain Size
2. Grid Specifications (Discretization size)
3. Structures
4. Sources
5. Monitors
6. Run time
7. Boundary Condition Specification

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

1 Computational Domain Size

Size in x, y, and z directions.

```
1 p = 0.666 #nm → Periodicity
2 Lx, Ly, Lz = p, p, 2 * lda0
3 sim_size = [Lx, Ly, Lz]
4
5 # Defining a simulation
6 simulation1 = td.Simulation(
7     # A square computational domain
8     size = sim_size
9 )
```


2 Grid Specifications

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

```
1  # Define Grid size
2  spec = td.GridSpec.auto(min_steps_per_wvl=40, wavelength=lda0)
3
4  # Defining a simulation
5  simulation1 = td.Simulation(
6      # A square computational domain
7      size = (x, y, z),
8      grid_spec=spec,
9
10 )
```

- 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:

```
1 td.GridSpec.uniform(dl=grid_size)
2 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 tuple of **Structure** objects that you create.

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

```
1 # set up simulation
2 td.Structure(
3     # inputs
4 )
```

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:

```
1 t = 2 # thickness of the substrate # THIS SHOULD BE CHANGED TO INFINITE
2 substrate = td.Structure(
3     geometry=td.Box(
4         center=(0,0,-t/2),
5         size=(td.inf,td.inf,t)
6     ),
7     medium=td.Medium(permittivity=1.45**2, name='oxide'),
8     name='substrate'
9 )

1 superstrate = td.Structure(
2     geometry=td.Box(
3         center=(0,0,t/2),
4         size=(td.inf,td.inf,t)
5     ),
6     medium=td.Medium(permittivity=1.4**2, name='glass'),
7     name='superstrate'
8 )

1 polymer = td.Structure(
2     geometry=td.Box(
3         center=(0,0,0),
4         size=(td.inf,td.inf,2*t)
5     ),
6     medium=td.Medium(permittivity=1.66**2, name='polymer'),
7     name='polymer'
8 )
```



4 Sources

Tuple of electric current sources injecting fields into the simulation.
Common ones are:

Plane Wave – Uniform current distribution on an infinite extent plane. (Doc)

```
1 pulse = GaussianPulse(freq0=200e12, fwidth=20e12)
2 pw_source = PlaneWave(size=(inf,0,inf), source_time=pulse, pol_angle=0.1, direction='+')
```

Point Dipole – Uniform current source with a zero size. (Doc)

```
1 pulse = td.GaussianPulse(freq0=200e12, fwidth=20e12)
2 pt_dipole = td.PointDipole(center=(1,2,3), source_time=pulse, polarization='Ex')
```

See documentation for **Other Sources**

In this case, I defined one plane wave source:

```
1  # add a plane wave source
2  plane_wave = td.PlaneWave(
3      source_time=td.GaussianPulse(freq0=freq0, fwidth=0.5 * freqw),
4      size=(td.inf, td.inf, 0),
5      center=(0, 0, 0.3 * lda0),
6      direction="-",
7      pol_angle=0,
8  )
```

5 Monitors

Tuple of monitors in the simulation. Note: monitor names are used to access data after simulation is run.

See **Other monitors**

6 Run time

Total electromagnetic evolution time in seconds.

7 Boundary Condition Specification

Specification of boundary conditions along each dimension. If None, PML boundary conditions are applied on all sides.

Bonus: Symmetry

Tuple of integers defining reflection symmetry across a plane bisecting the simulation domain normal to the x-, y-, and z-axis at the simulation center of each axis, respectively. Each element can be 0 (no symmetry), 1 (even, i.e. 'PMC' symmetry) or -1 (odd, i.e. 'PEC' symmetry). Note that the vectorial nature of the fields must be taken into account to correctly determine the symmetry value.

Symmetry can be used to greatly reduce the computational cost →

Tidy3D

Structure



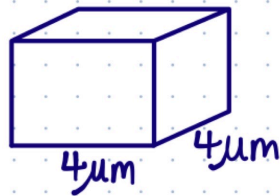
FIRST WALKTHROUGH

PLANE WAVE ON
DIELECTRIC SLAB WITH
TRIANGULAR PILLAR.

PML EXTENDS OUTSIDE

USER-DEFINED DOMAIN.

$\text{SIMSIZE} = [4, 4, 4]$



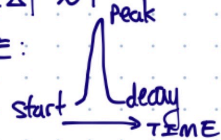
Runtime

DEPENDS ON

- ①. LONG-LIVED RESONANCES
- ②. BANDWIDTH

$$\Delta f \sim 1$$

PULSE:



$$\text{PULSE WIDTH} \sim \frac{1}{\text{Bandwidth}}$$

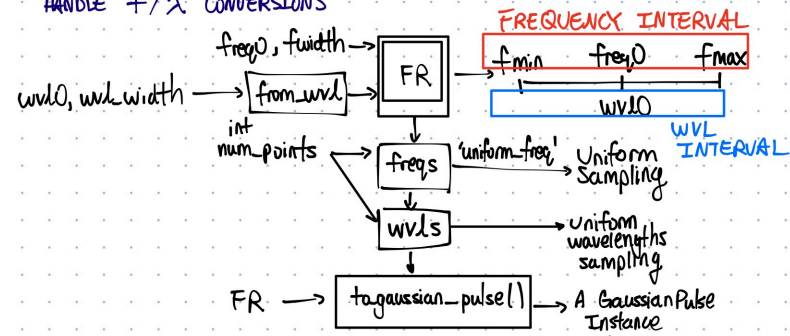
$$\text{Runtime} = \frac{n}{\text{width}} \forall n \in \mathbb{Z}^+$$

$$n = 2, 3, 4, \dots$$

GOAL: JUST ENOUGH
TO CAPTURE TAIL

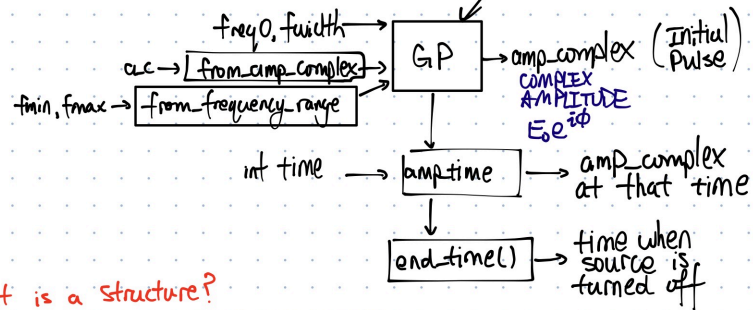
FreqRange

CONVENIENCE CLASS
HANDLE f/λ CONVERSIONS



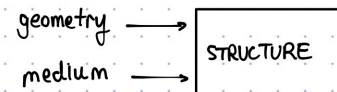
What is GaussianPulse?

SOURCE TIME DEPENDENCE



What is a structure?

A MEDIUM WITH A GEOMETRY



IF STRUCTURE SIZE > DOMAIN SIZE,
AUTOMATIC TRUNCATION.
USE `td.inf` (infinite) WHEN EXTENDING
TO SIMULATION EDGES/ABSORBING BOUNDARIES.

what is a Plane Wave Source?

