# Learning Tidy3D

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# Lecture Outline

- Introduction to Tidy3D

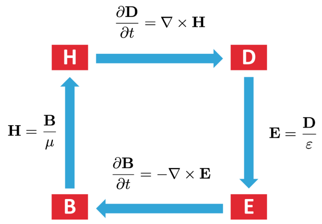
# Introduction

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** ($\mu m$)

# Basic Workflow

Here’s how to simulate something:

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

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

```python
# 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.

See Simulation Documentation for more information

# 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.

```python
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.

```python
# 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:

```
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 tuple 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:

```
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'
)
```

```
# construct the silicon resonator
```

# 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)

```
pulse = GaussianPulse(freq0=200e12, fwidth=20e12)
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)

```
pulse = td.GaussianPulse(freq0=200e12, fwidth=20e12)
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:

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

# 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 –>