P&S COMSOL® Design Tool

Lecture Week 3: Introduction to COMSOL

Taichiro Fukui, Maximilian Bosch

Content

- Software & Physics
- Meshing
- Boundary Conditions
- Source
- Tutorial 3: Young’s Slit Experiments

Software & Physics

Software & Physics

Simulation Software

Simulation Method

Finite Element Method (FEM)

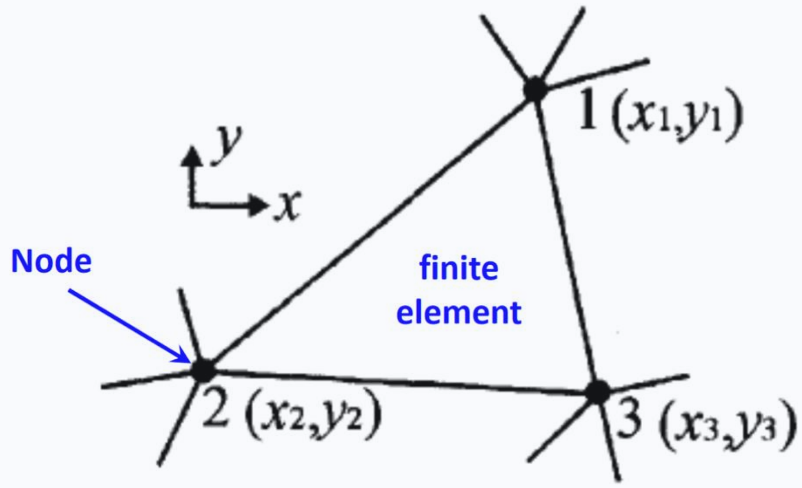
Finite Difference Time Domain (FDTD)

Taichiro Fukui fukui@ief.ee.ethz.ch
Maximilian Bosch bosch@ief.ee.ethz.ch

Software & Physics

Software & Physics

FEM
1. *Division of space into finite elements*
   - *Local refinement*
   - *Almost perfectly conformal*
2. *Formulation of a boundary value problem*
   - *Field calculated at the node and interpolated at edges*
3. *Elimination of time derivatives (steady state)*



Advantages of FEM

+ Flexible geometry and meshing
+ Accuracy specification
+ Good for frequency-domain problems
+ Material properties

Disadvantages of FEM

– Complexity
– Large computational power especially for 3D
– Bandwidth

Software & Physics

Software & Physics

$$\frac{\partial \mathbf{E}}{\partial t} = \frac{1}{\epsilon}(\nabla \times \mathbf{H} - \mathbf{J})$$

$$\frac{\partial \mathbf{H}}{\partial t} = -\frac{1}{\mu}\nabla \times \mathbf{E}$$

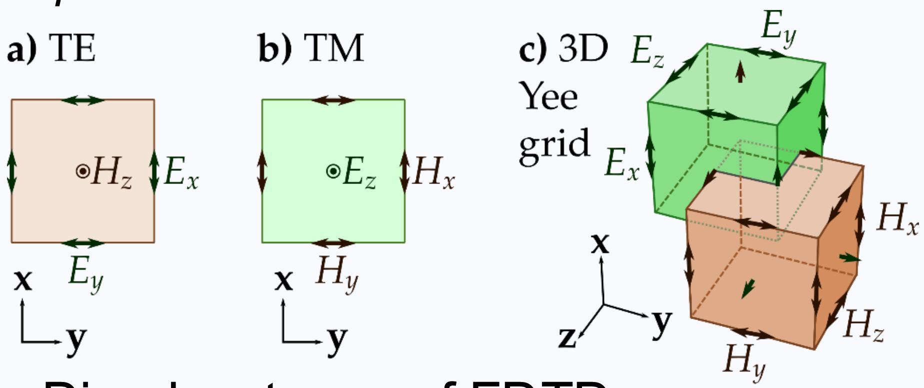
$$\Rightarrow$$

$$H^{n+1/2} = H^{n-1/2} - \frac{\Delta t}{\mu}(\nabla \times E^n)$$

$$E^{n+1} = E^n + \frac{\Delta t}{\epsilon}(\nabla \times H^{n+1/2} - J)$$

<u>FDTD</u>

1. *Replace derivative with finite difference, discretize in space and time*
2. *Solve resulting difference equations*
3. *Evaluate magnetic field one time-step in future*
4. *Evaluate electric field one time-step in future*
5. *Repeat the previous two steps*



<u>Advantages of FDTD</u>

+ Intuitive, direct usage of E- and H-Fields
+ Nonlinear problems
+ Time-domain, good for broadband problems
+ Animated display of evolving fields, suited for wave propagation

<u>Disadvantages of FDTD</u>

– Rectangular mesh
  – Conformality and refinement
– Material boundaries
– Memory requirement
– Modeling for strong resonances (high Q)

Taichiro Fukui fukui@ief.ee.ethz.ch
Maximilian Bosch bosch@ief.ee.ethz.ch

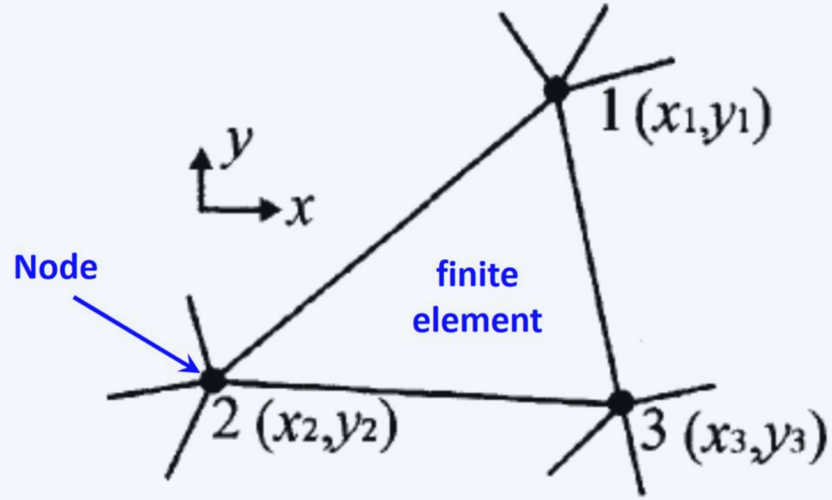
Meshing

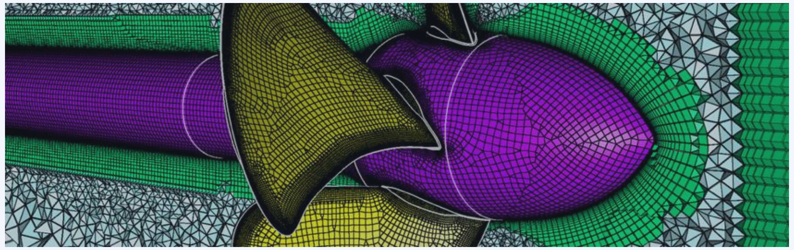
Software & Physics

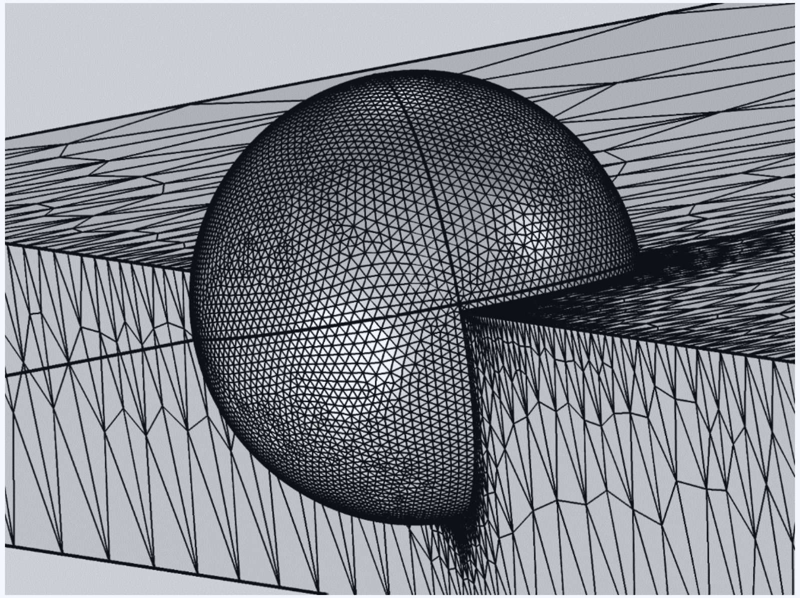
FEM, FDTD, BEM…

Frequency Domain,
Acoustics, Fluids,
Plasma, etc

Domain & Mesh







Meshing

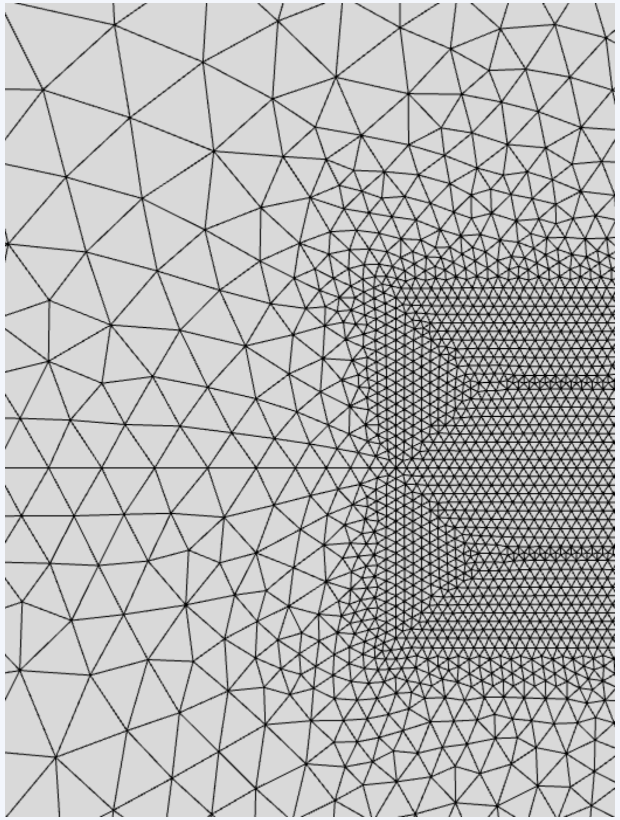
Software & Physics

FEM, FDTD, BEM…

Frequency Domain,
Acoustics, Fluids,
Plasma, etc

Domain & Mesh

- Discretization of simulation domain
- Mesh size determines accuracy of solution
  - Too large mesh → wrong results
- Accuracy vs. simulation time
  - Too small mesh → very large simulation time
  - If RAM is too low, data is written onto hard drive → ultra large simulation time



Taichiro Fukui fukui@ief.ee.ethz.ch
Maximilian Bosch bosch@ief.ee.ethz.ch

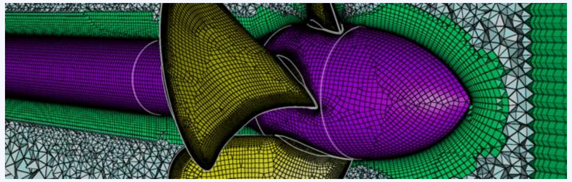
Boundary Conditions

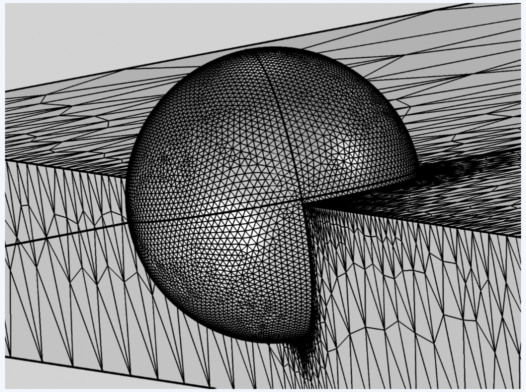
Software & Physics

FEM, FDTD, BEM…

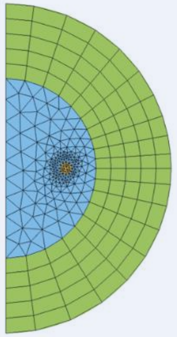
Frequency Domain,
Acoustics, Fluids,
Plasma, etc

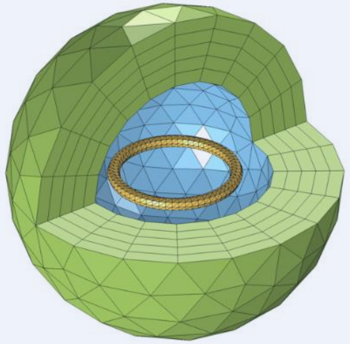
Domain & Mesh

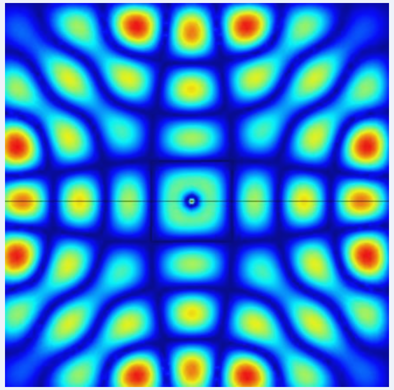




Boundary Conditions





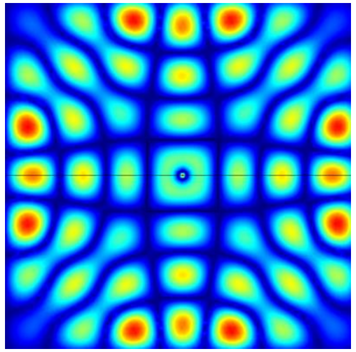


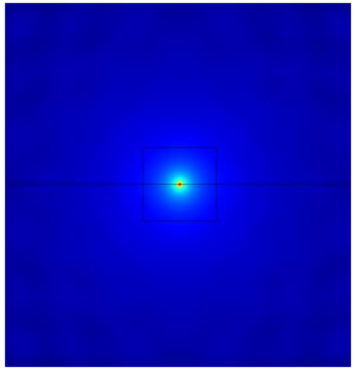
Types of boundary conditions in COMSOL
- Perfect Electric Conductor (PEC)
- Perfect Magnetic Conductor (PMC)
- Scattering Boundary Condition
- Periodic Boundaries Condition (PBC)
- Perfectly Matched Layer (PML)

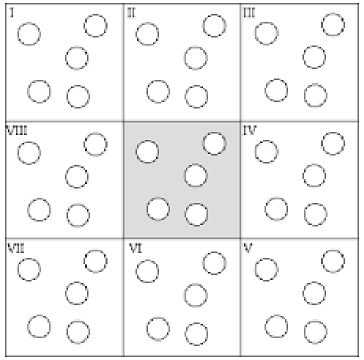
Taichiro Fukui fukui@ief.ee.ethz.ch
Maximilian Bosch bosch@ief.ee.ethz.ch

Boundary Conditions

- **Perfect Electric Conductor (PEC)**
  - Properties
    - Electric field cannot penetrate → reflection of electric field
    - Equivalent to infinite electric conductivity
- **Perfect Magnetic Conductor (PMC)**
  - Properties
    - Magnetic field cannot penetrate → reflection of magnetic field
    - Equivalent to infinite magnetic conductivity
- **Scattering Boundary Condition**
  - Properties
    - Electric field is absorbed → no reflection
- **Periodic Boundary Condition**
  - For repeating structures
  - Use a unit cell for the analysis
  - Simulates systems expanding infinitely in 1D/2D







Taichiro Fukui fukui@ief.ee.ethz.ch
Maximilian Bosch bosch@ief.ee.ethz.ch

Source

Software & Physics

COMSOL

lumerical

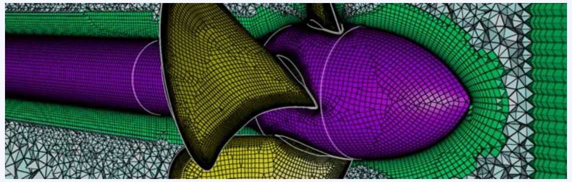
cadence

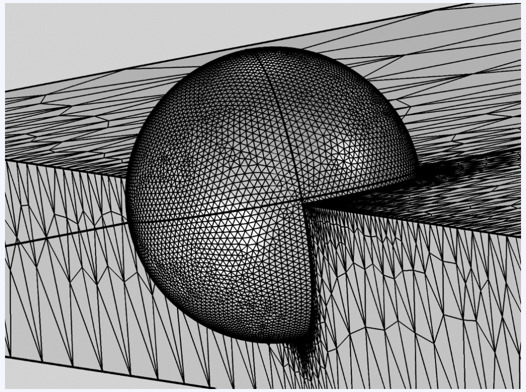
MATLAB

FEM, FDTD, FDFD, FEM, BEM

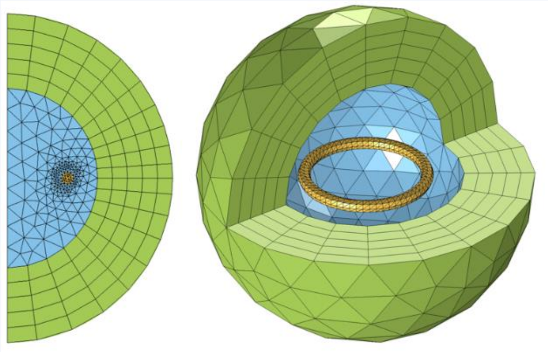
Frequency Domain, Acoustics, Fluids, Plasma, etc

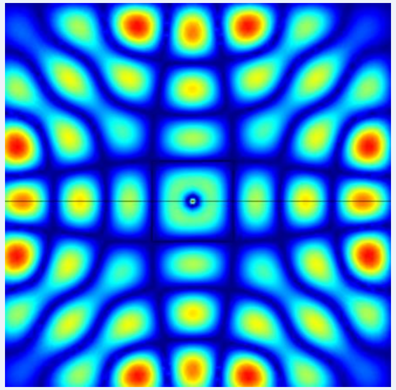
Domain & Mesh



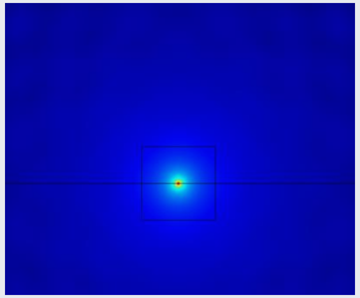


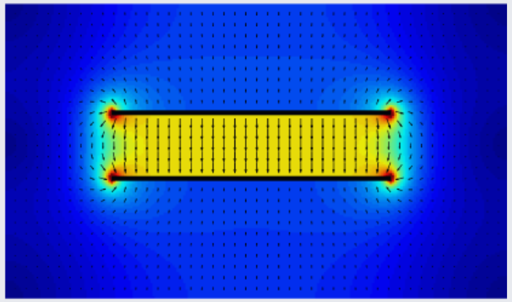
Boundary Condition

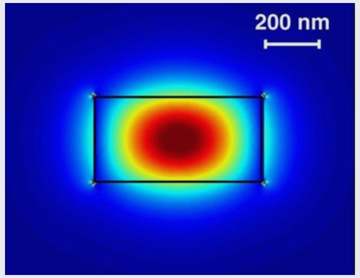




Source







Taichiro Fukui fukui@ief.ee.ethz.ch
Maximilian Bosch bosch@ief.ee.ethz.ch

P&S COMSOL® Design Tool

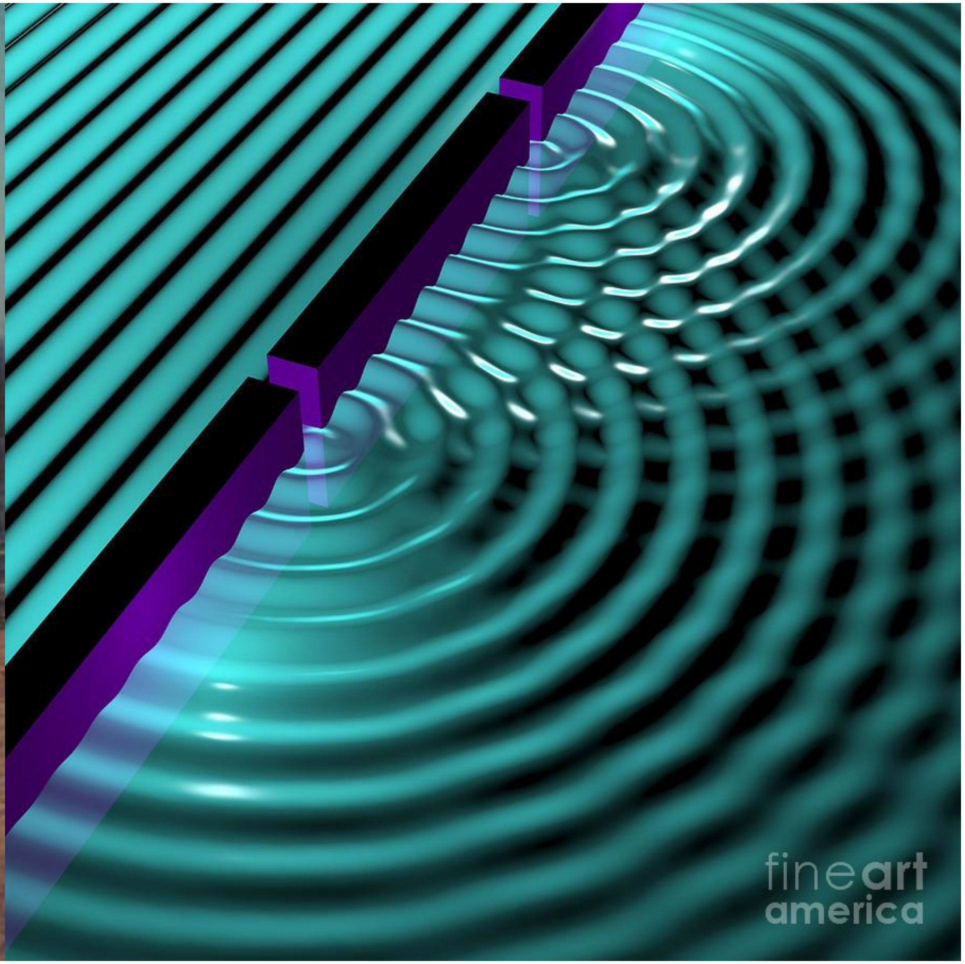
Exercise Week 3: Young's Slit Experiments

Taichiro Fukui, Maximilian Bosch

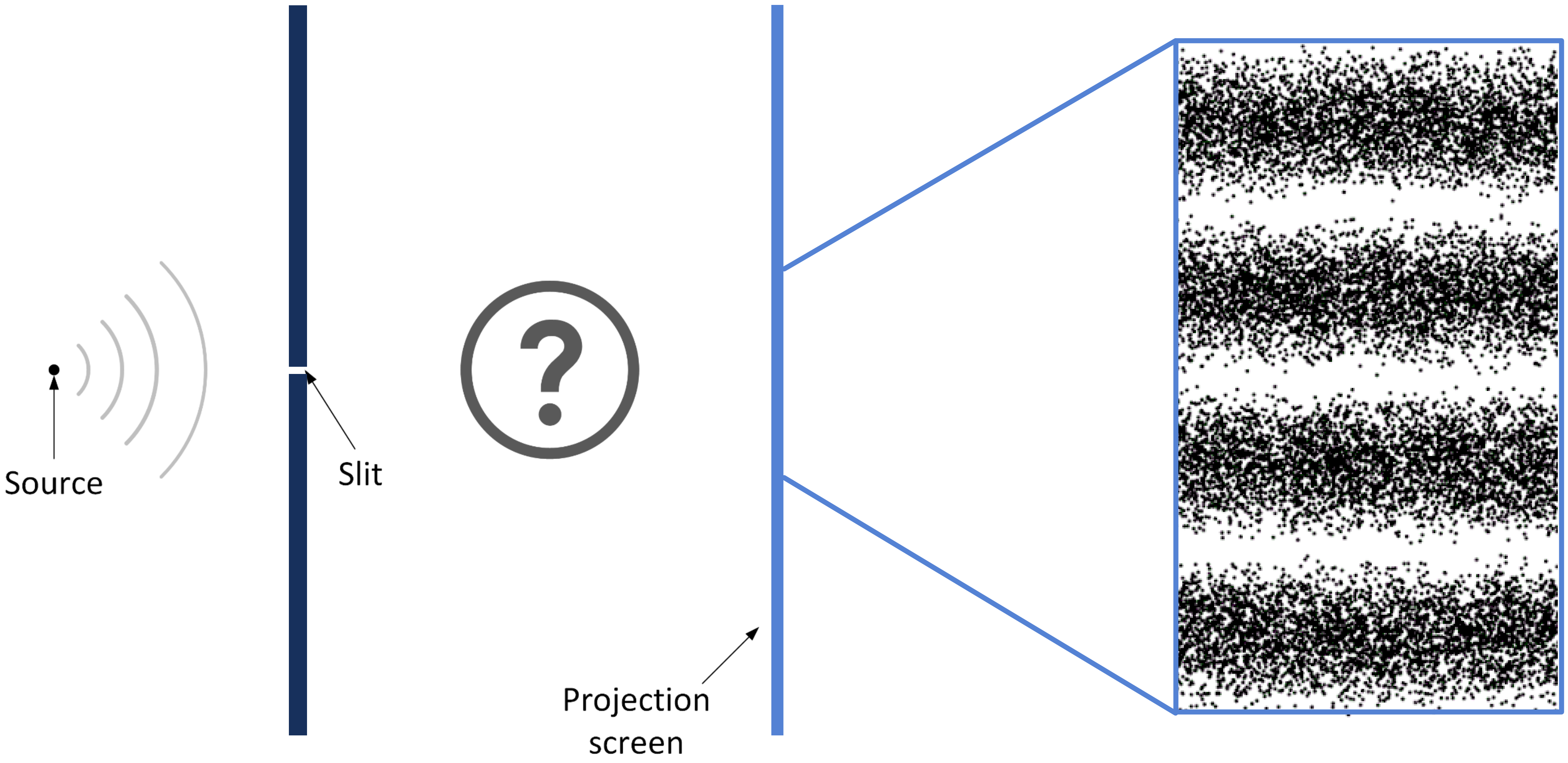
Content

- Tutorial 3: Young's Slit Experiments
  - Single slit
    - Theory
    - Simulation
  - Double slit
    - Theory
    - Simulation

Young's Slit Experiment: Single Slit

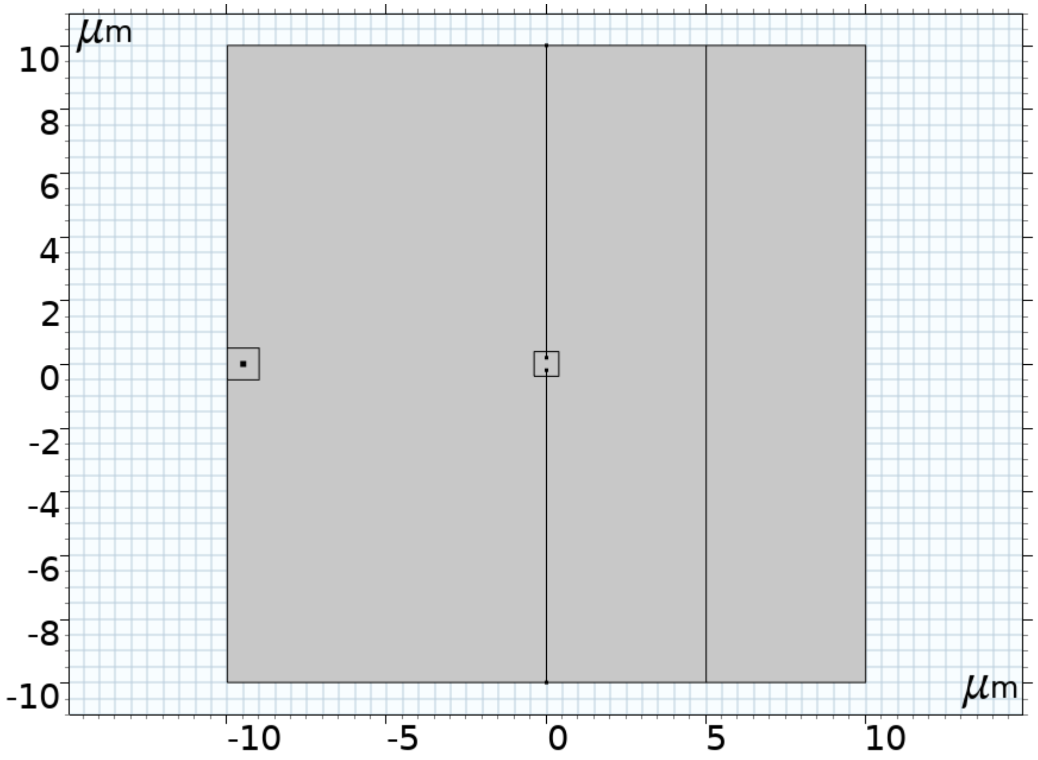


Young's Slit Experiment: Single Slit

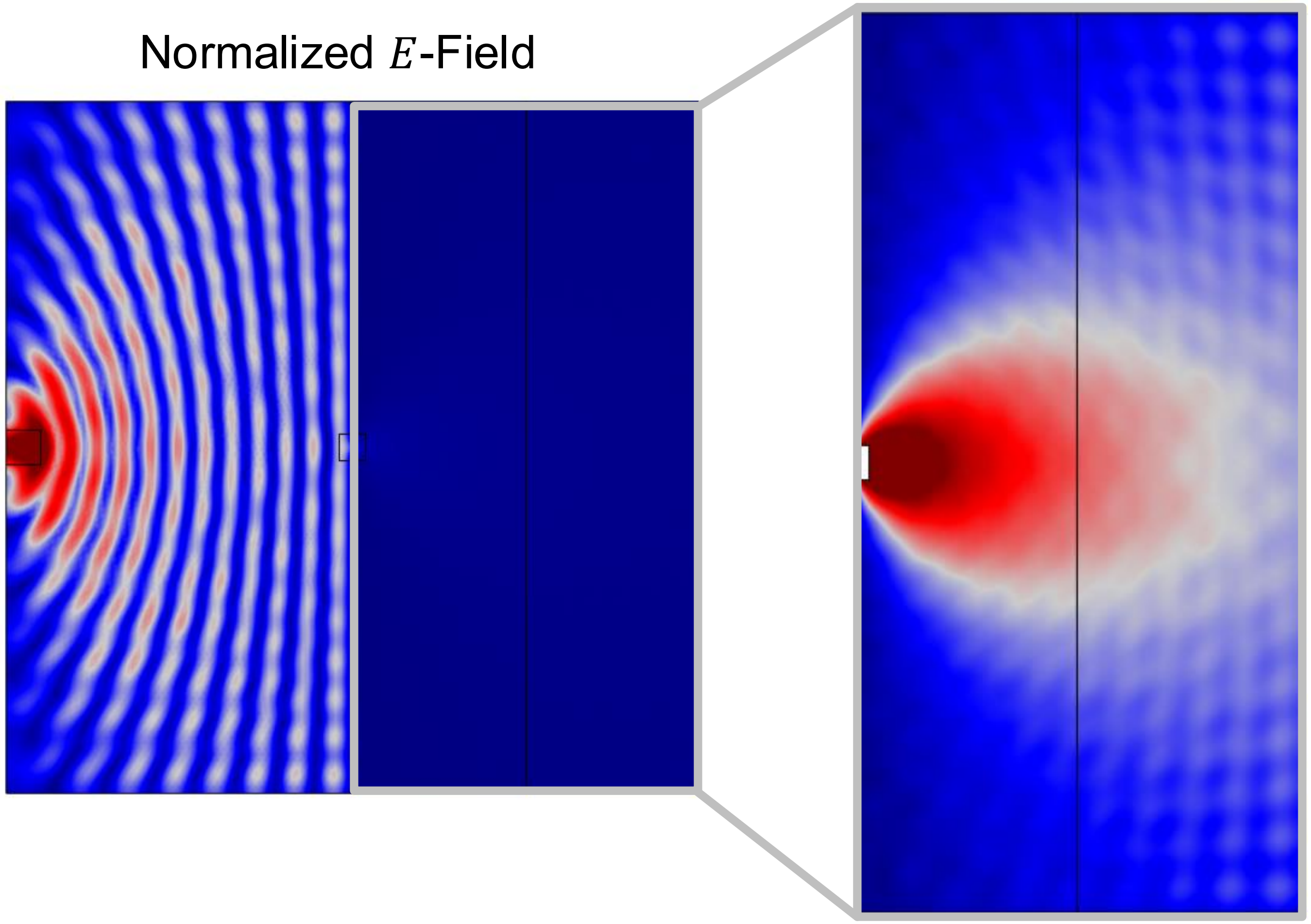


Taichiro Fukui fukui@ief.ee.ethz.ch
Maximilian Bosch bosch@ief.ee.ethz.ch

Single Slit Point Source

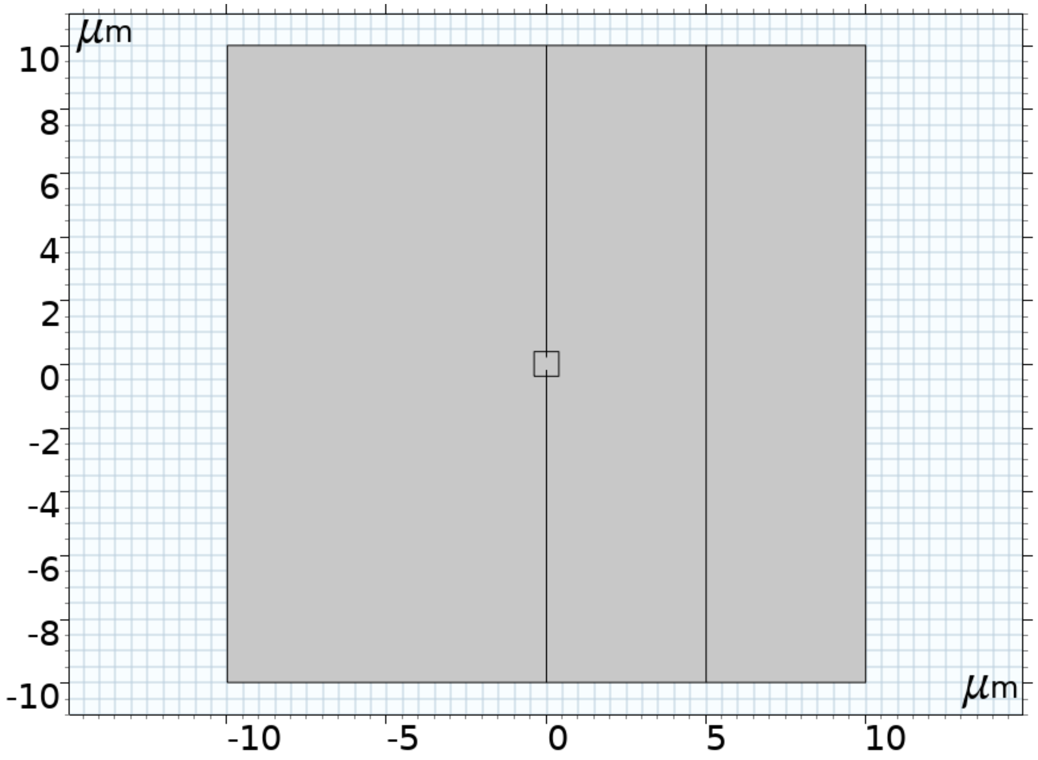


Normalized E-Field

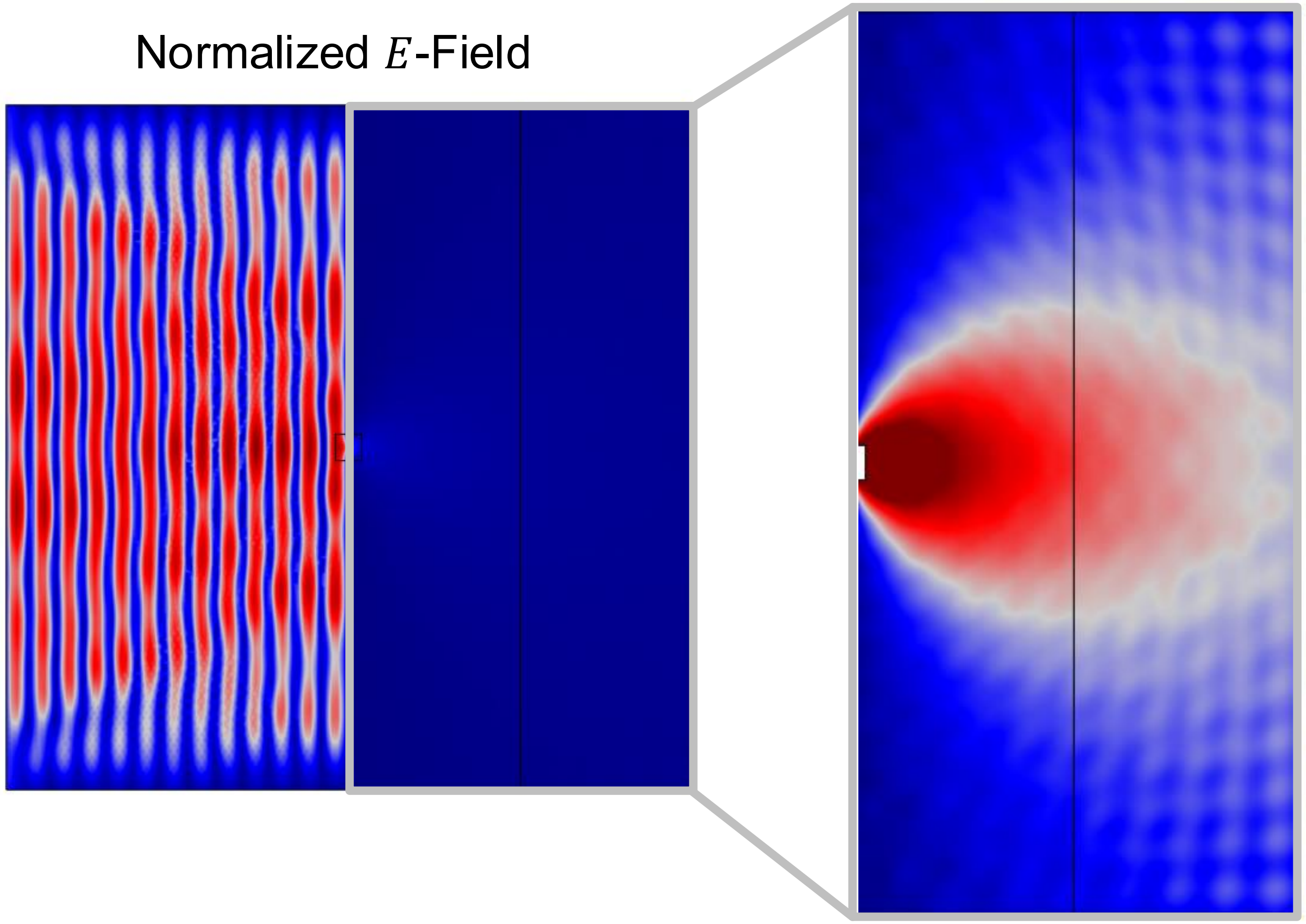


Taichiro Fukui fukui@ief.ee.ethz.ch
Maximilian Bosch bosch@ief.ee.ethz.ch

Single Slit Plane Wave



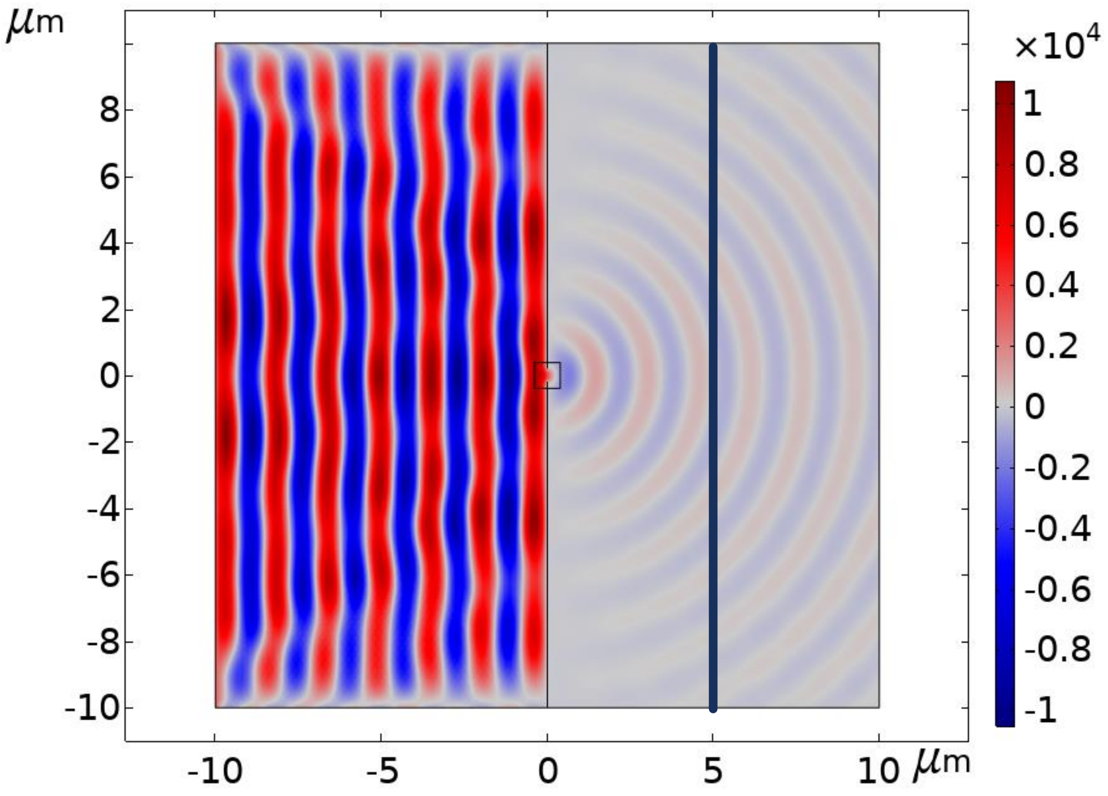
Normalized E-Field

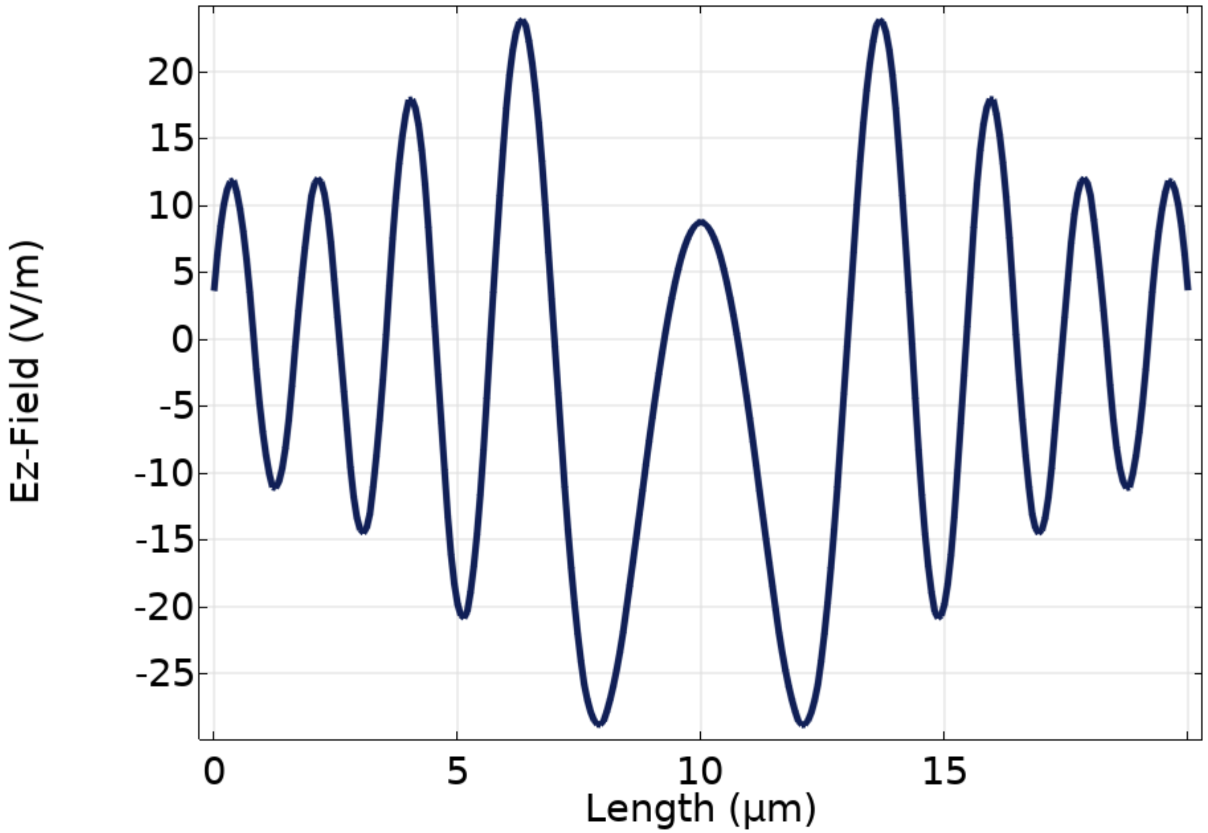


Taichiro Fukui fukui@ief.ee.ethz.ch
Maximilian Bosch bosch@ief.ee.ethz.ch

Single Slit Plane Wave

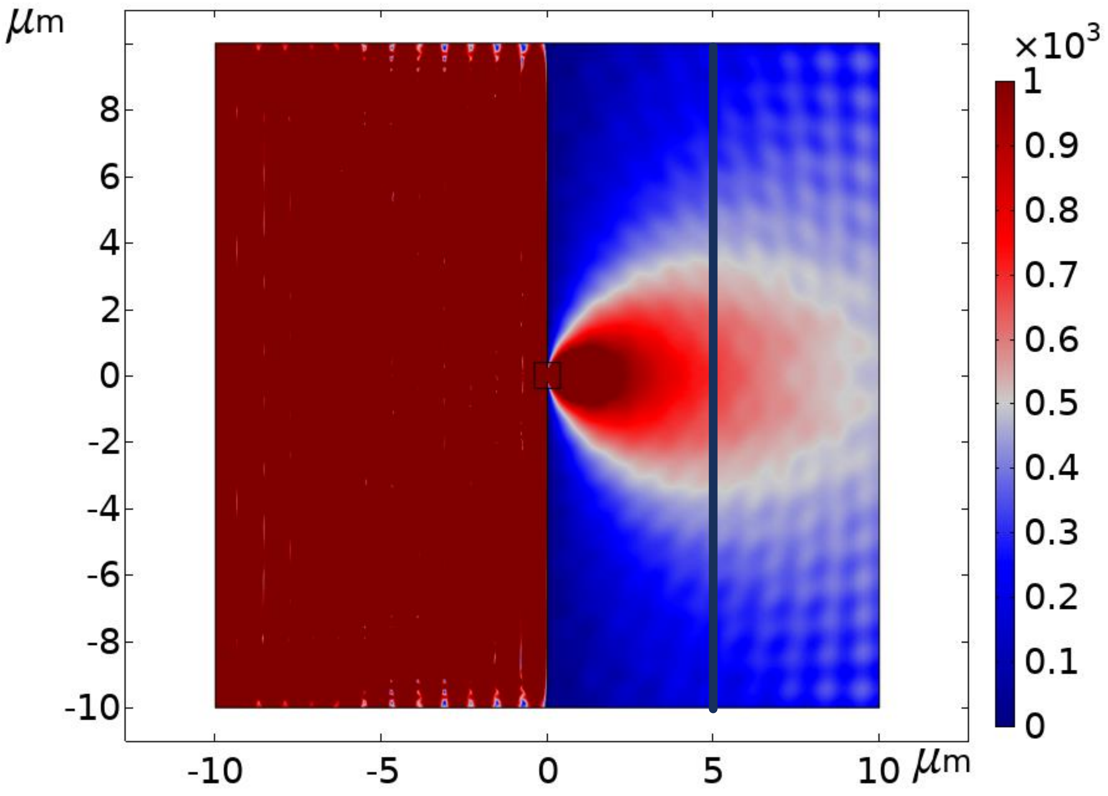
E_z-Field

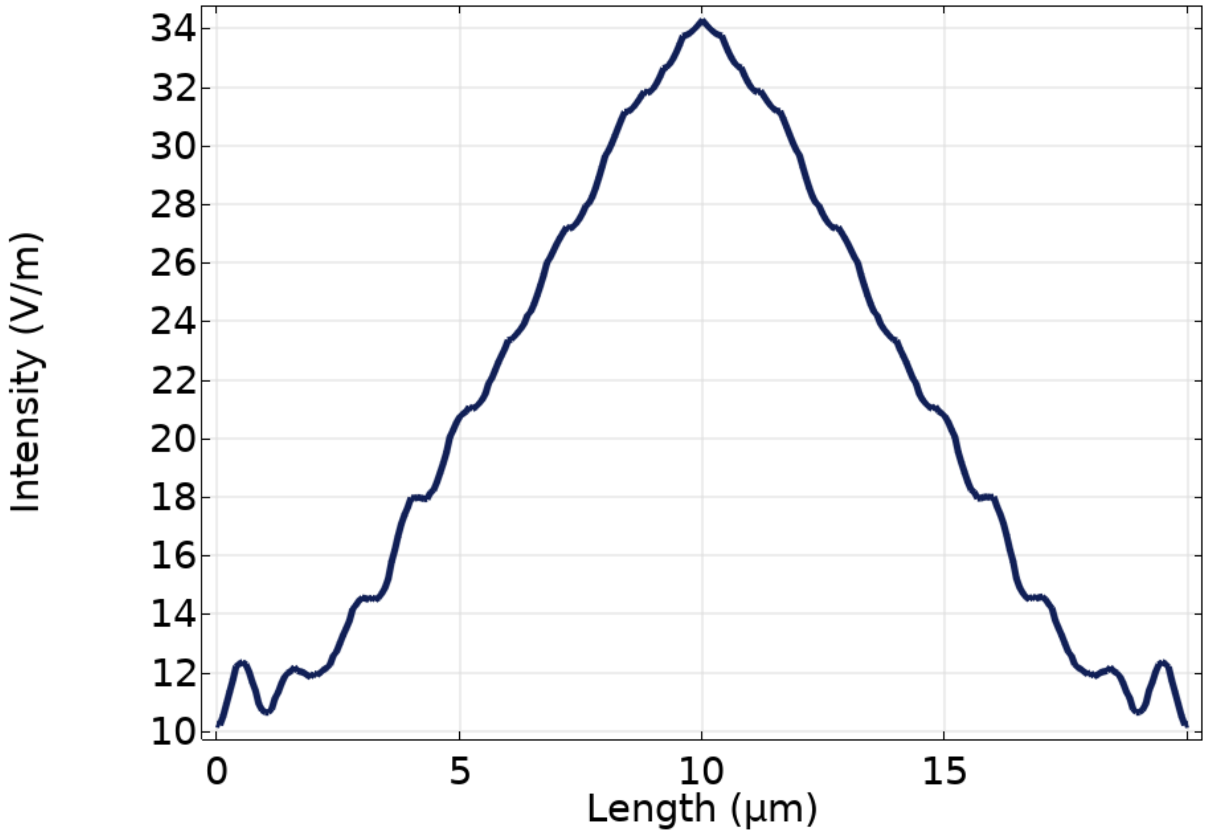




Single Slit Plane Wave

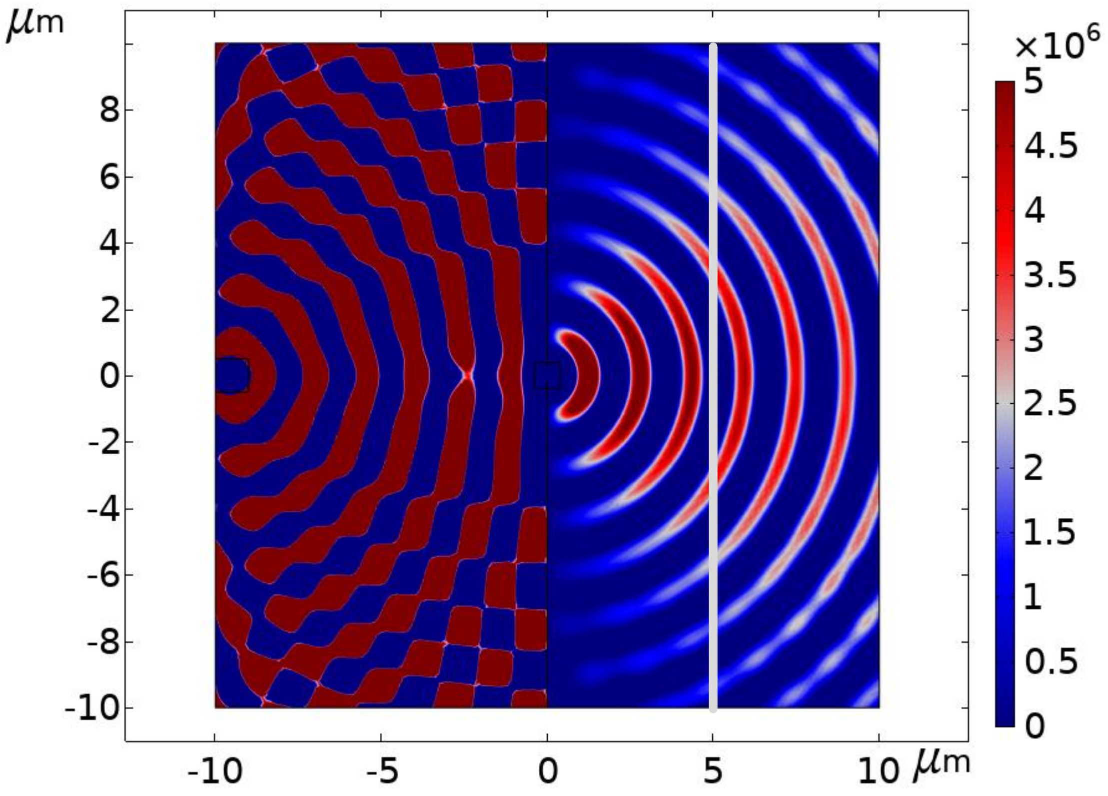
Intensity: $\sqrt{|E_z|^2}$

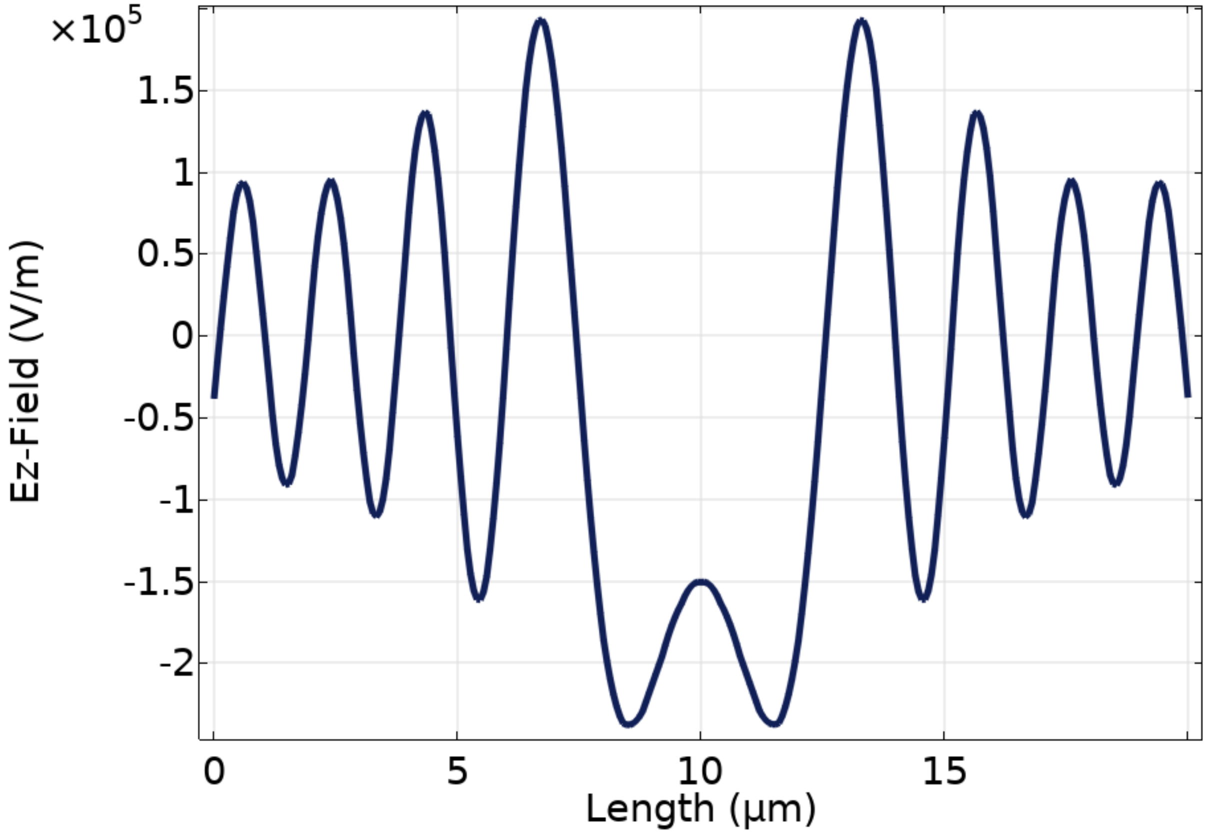




Single Slit Plane Wave

E_z-Field





Taichiro Fukui fukui@ief.ee.ethz.ch
Maximilian Bosch bosch@ief.ee.ethz.ch

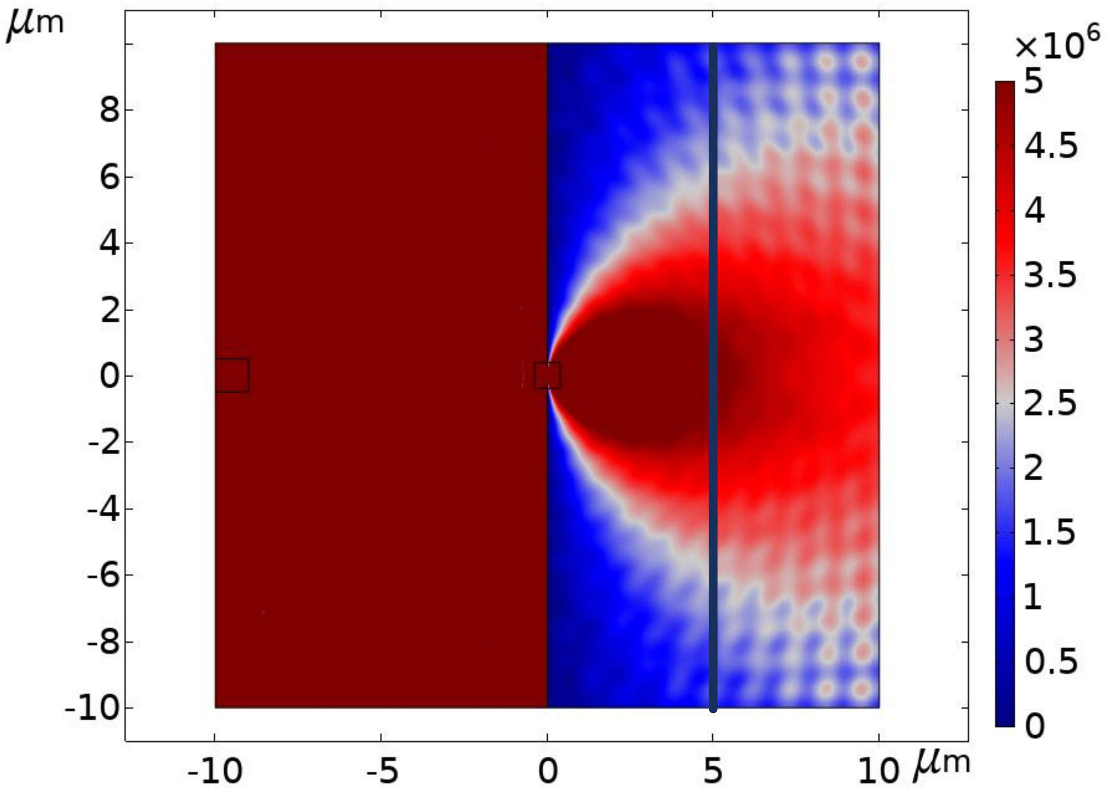
Single Slit Plane Wave

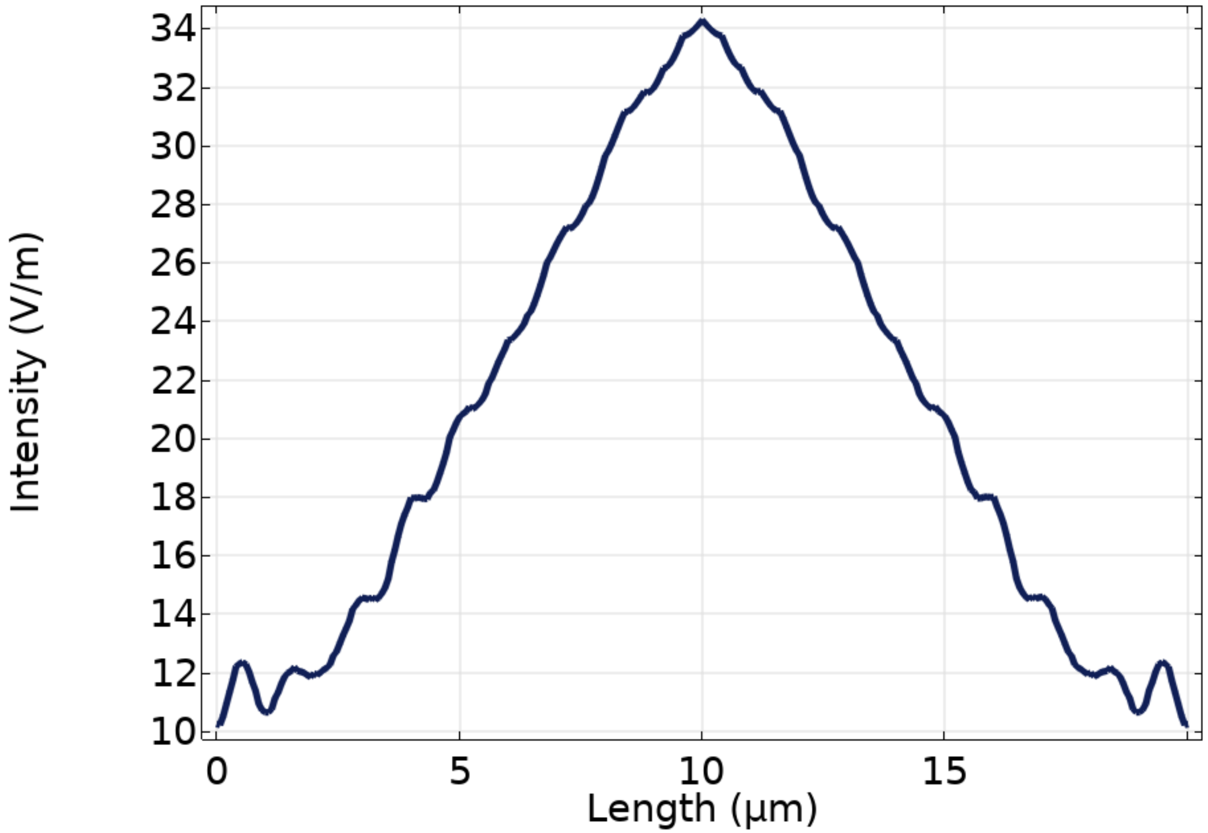
domain_x	20[um]	2E-5 m	length domain
domain_y	20[um]	2E-5 m	width domain
lam0	1550[nm]	1.55E-6 m	wavelength
f0	c_const/lam0	1.9341E14 1/s	frequency
slit_width	lam0/4	3.875E-7 m	slit width
sep	5[um]	5E-6 m	seperation
screen	5[um]	5E-6 m	location of screen
source_x	-9.5[um]	-9.5E-6 m	location of point source
source_box	1[um]	1E-6 m	mesh refinement point source

Taichiro Fukui fukui@ief.ee.ethz.ch
Maximilian Bosch bosch@ief.ee.ethz.ch

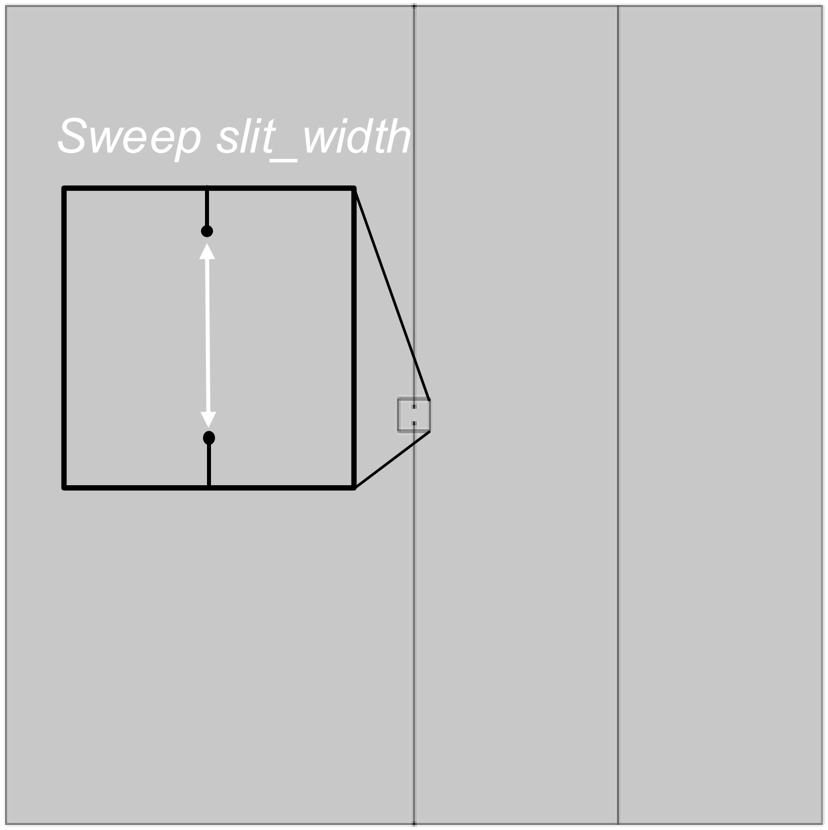
Single Slit Plane Wave

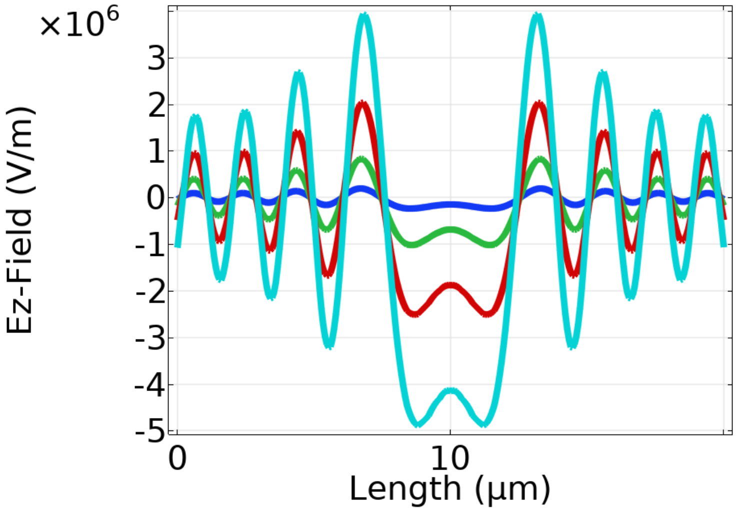
Amplitude: $\sqrt{|E_z|^2}$

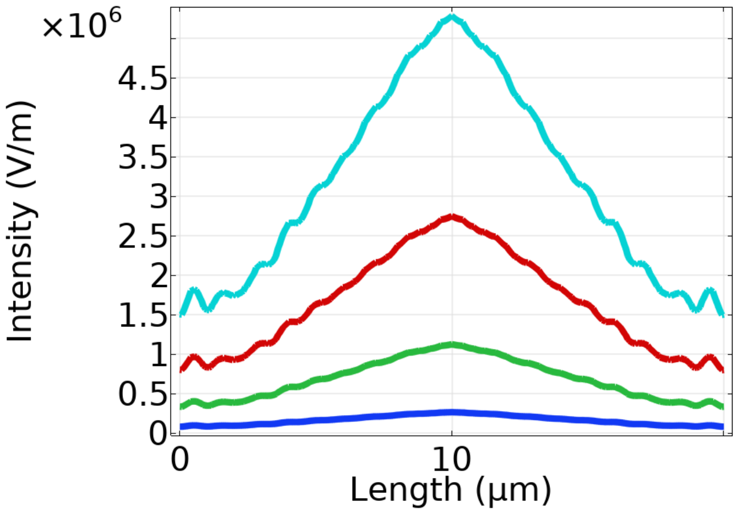




Young's Slit Experiment: Single Slit – Parametric Sweep Results







Taichiro Fukui fukui@ief.ee.ethz.ch
Maximilian Bosch bosch@ief.ee.ethz.ch

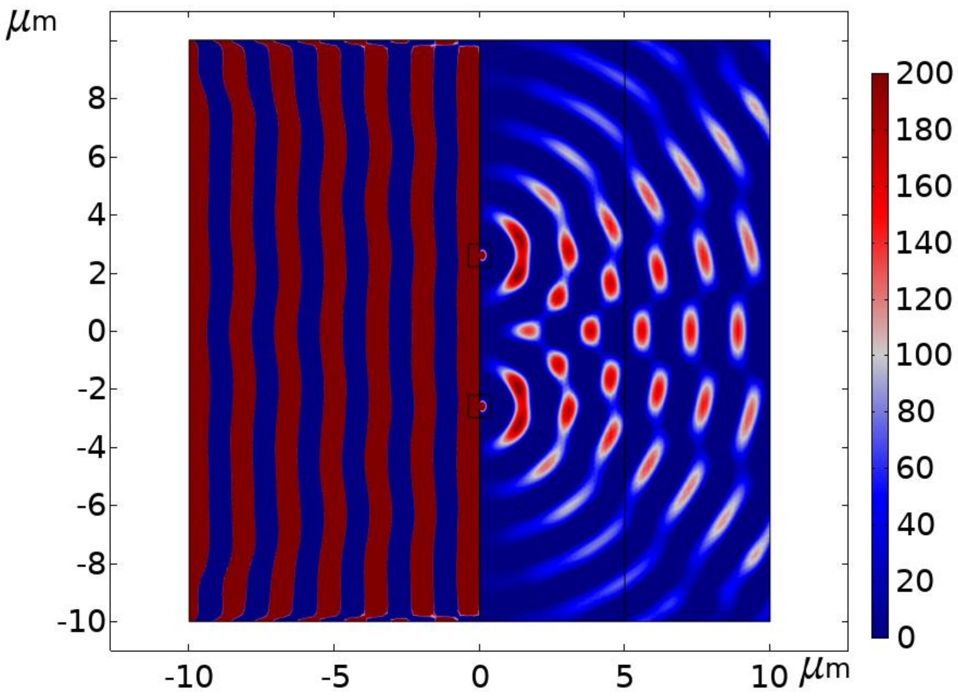
Young’s Slit Experiment: Single Slit – Parametric Sweep Results

Let’s take a look at COMSOL

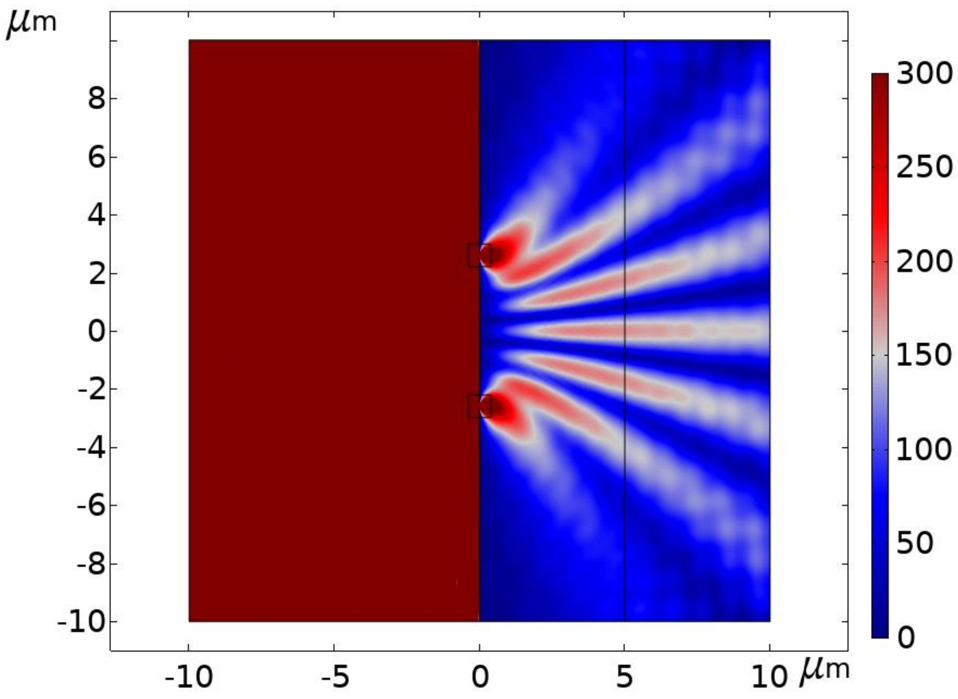
Taichiro Fukui fukui@ief.ee.ethz.ch
Maximilian Bosch bosch@ief.ee.ethz.ch

Young's Slit Experiment: Double Slit – Theory

E_z-Field



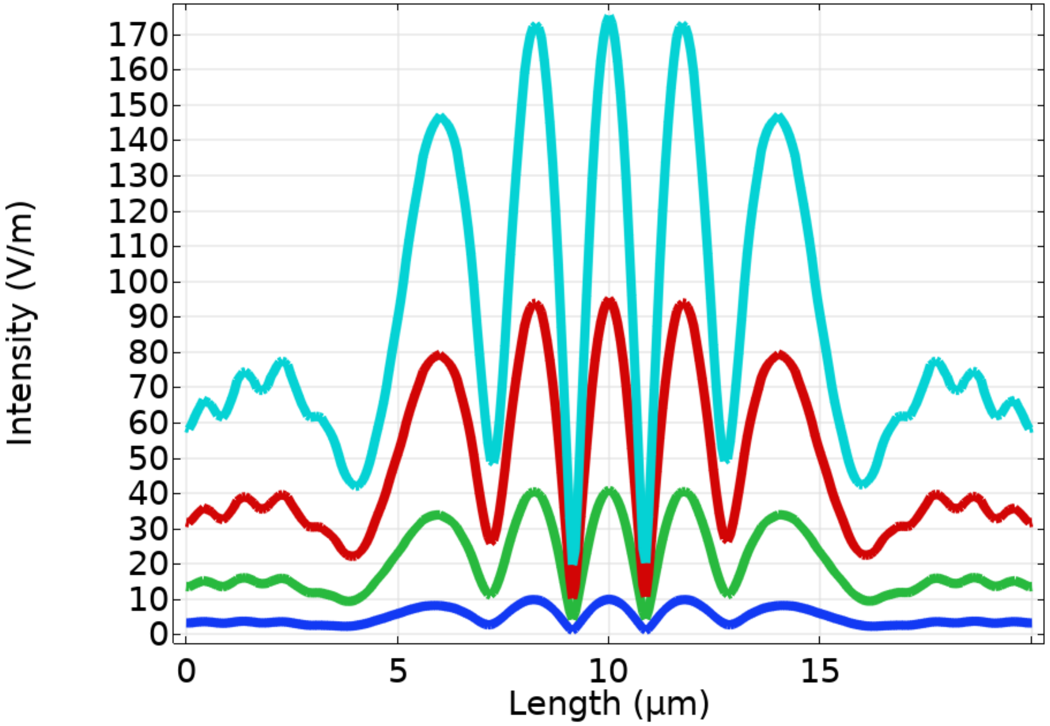
Amplitude: $\sqrt{|E_z|^2}$



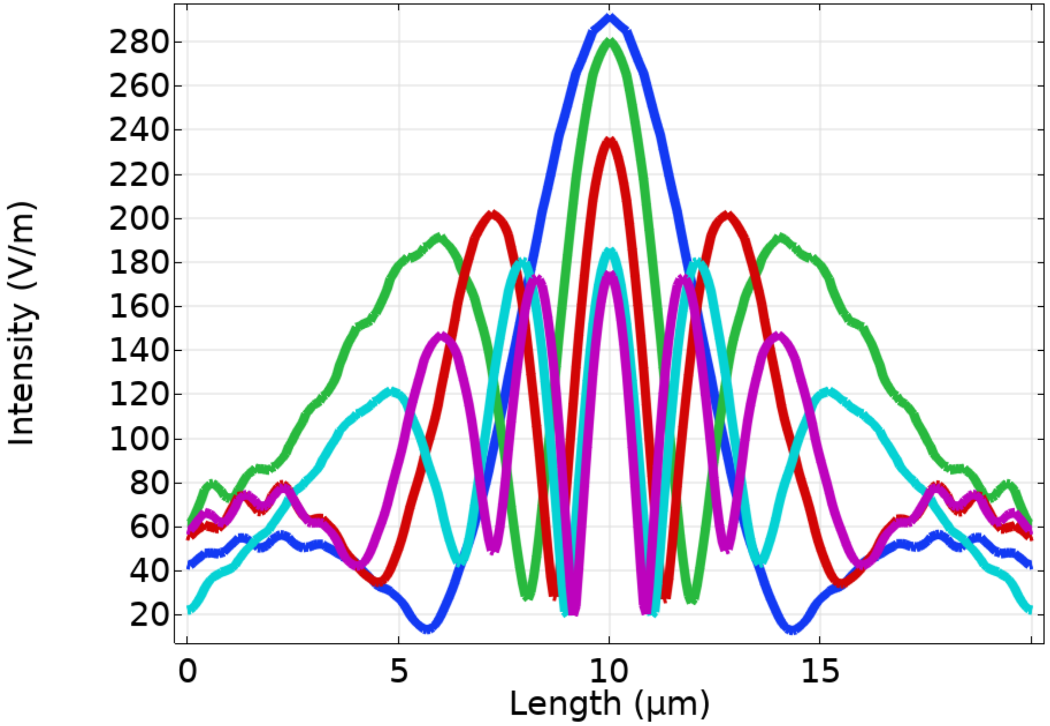
Taichiro Fukui fukui@ief.ee.ethz.ch
Maximilian Bosch bosch@ief.ee.ethz.ch

Young's Slit Experiment: Double Slit – Theory

Gapsweep $\left(\frac{lam0}{16} \rightarrow \frac{lam0}{4}\right)$, step: $\left(\frac{lam0}{16}\right)$



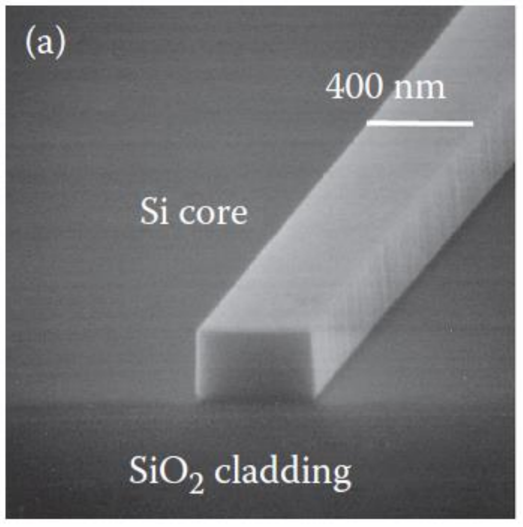
Separation Sweep 1 → 5 μm , step: 1 μm



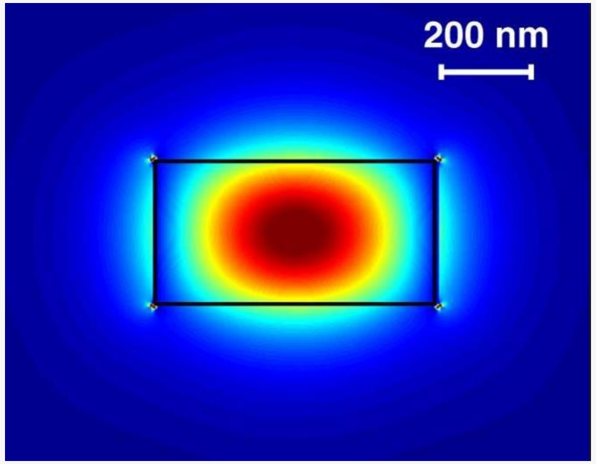
Taichiro Fukui fukui@ief.ee.ethz.ch
Maximilian Bosch bosch@ief.ee.ethz.ch

Next Week

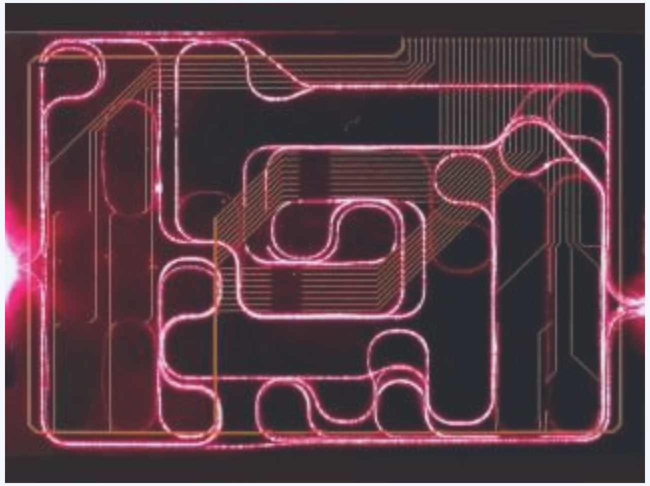
Photonic Waveguide

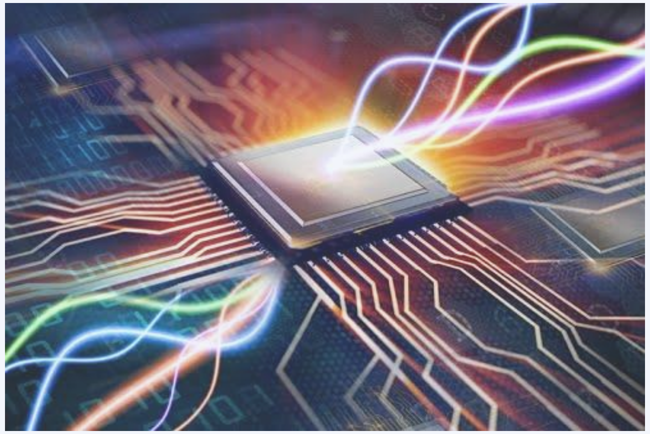


Mode Analysis



Photonic Integrated Circuits





Taichiro Fukui fukui@ief.ee.ethz.ch
Maximilian Bosch bosch@ief.ee.ethz.ch