Engineering Tripos Part IIA Project, SB4: Modeling of integrated photonic components, 2025-26

Leader

Dr Q Cheng [1]

Aims

The aims of the course are to:

- Understand Fundamental Theories: Gain a solid understanding of key concepts in photonics, including Maxwell's equations, waveguides, modes, FDTD models, and boundary conditions.
- Master Eigenmode Analysis: Learn to solve for eigenmodes in silicon waveguides using theoretical methods and Lumerical FDTD, and understand their physical significance.
- Develop Proficiency in Photonic Simulations: Acquire hands-on experience with Lumerical FDTD to set up, run, and analyze simulations, including basic waveguides and complex photonic components.
- Design, Simulation, and Validation: Gain the ability to design, simulate, and analyze photonic components such as directional couplers and MMIs, and validate simulation results by comparing them with mathematical models.

Objectives

As specific objectives, by the end of the course students should be able to:

- Understand the working principles and simulation methodologies for two key photonic components — directional couplers and multimode interferometers (MMIs), including mode coupling theory and multimode interference.
- Design and simulate a 2x2 directional couplers and a 2x2 MMI, optimizing their performance metrics such as coupling efficiency, insertion loss, and bandwidth.
- Validate simulation results by comparing them with analytical models and numerical methods, ensuring accuracy and reliability in predicting device behavior and performance. Discuss the current design limitation and possible improvement.
- Apply acquired knowledge and skills to practical scenarios, preparing for advanced studies or professional applications in photonics, such as communications, sensing, and signal processing.

Content

This four-week course on photonics simulation, designed for bachelor students, provides a comprehensive introduction to both theoretical and practical aspects of photonics. The course begins with an overview of fundamental photonics concepts, including Maxwell's equations, waveguides, and eigenmodes. Students will learn to derive waveguide modes using Maxwell’s equations and perform basic simulations.

In the second week, students will delve into eigenmode and mode propagation analysis in silicon waveguides, and design a single-mode waveguide utilizing both theoretical calculations and Lumerical FDTD simulations. This will provide a deeper understanding of mode characteristics and behavior in silicon waveguides.

The third week focuses on the design of two photonic components, i.e. a directional coupler and a MMI. Students will calculate key structural parameters and construct initial simulations of these components, gaining practical experience in photonic design and simulation techniques.

In the final week, students will optimize the performance of the designed components and validate their simulation results with mathematical models to ensure accuracy and reliability in their simulations. By the end of the course, students will be proficient in both the theoretical understanding and practical application of photonics simulations, preparing them for advanced studies or professional work in the field.

Week 1

Introduce fundamental photonics theory and basic waveguide simulation with Lumerical software, focusing on understanding and setting up simple models.

Week 2

Dive into eigenmode analysis in silicon waveguides using both theoretical calculations and Lumerical FDTD. Design and simulate a single-mode waveguide, observe the mode propagation, and compare it with the calculated single-mode condition.

Week 3

Design and simulate two waveguide photonic components — a directional coupler and an MMI. Calculate their key structural parameters using theoretical models, and simulate both components with Lumerical FDTD.

Week 4

Validate simulation results by comparing them with theoretical and numerical models, optimize their performance, ensuring accuracy and reliability of the simulations.

Mini Lectures:

Two mini lectures will be delivered to:
•Introduction to photonic fundamentals, Maxwell's equations, waveguide modes, and eigenmode analysis in photonic waveguides, such as silicon waveguide.
•Overview/tutorial of Lumerical FDTD software, including interface navigation, setting up simulations, and running and interpreting simulation results.

Coursework

Coursework	Due date
Interim report 1	TBD
Interim report 2	TBD
Final summary report	TBD

Examination Guidelines

Please refer to Form & conduct of the examinations [2].

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Links
[1] mailto:qc223@cam.ac.uk
[2] https://teaching.eng.cam.ac.uk/content/form-conduct-examinations