Microphotonics

CAD-Exam

Assignment

18/12/2023

Practicalities

This CAD-exam is **open book**: all course material and personal notes are allowed. You are allowed to ask questions to the supervisors. A separate online document will be provided where you can fill in your answers. Any form of communication is prohibited and you will be monitored through MS Teams. We ask you to record the simulation parameters that you use in this exam. The duration of the exam is limited to 3 hours. Please listen carefully to the explanation before starting the exam. Good luck!

1 Fourier optics

In this question, you will make use of MATLAB Fourier GUI. You can assume the lenses are **aberration free** and their diameter is so large that their limiting effect on the resolution of this system can be neglected. If not otherwise specified in the question, you can assume that **coherent light** is used at a wavelength of 1550 nm and all focal distances are fixed at 0.3 m. All files required are in the sub-folder `exam` of the provided zip-file.

1.1 1D optical convolution processor

(Use only **1D simulations** for this part. Use only **coherent illumination**.)
An optical convolution processor can be seen in Figure 1.

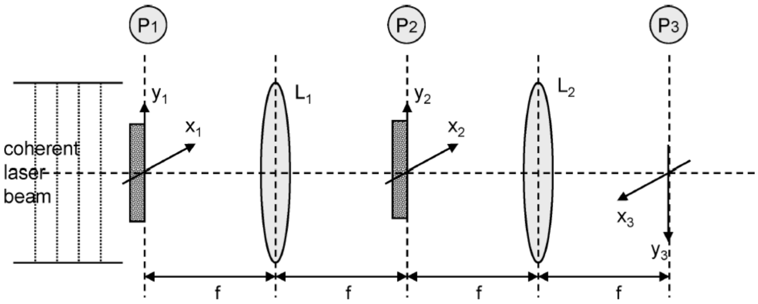

Figure 1: Optical convolution processor.

Given an aperture with the following 1D representation along one of its axes (Figure 2) along x_1:

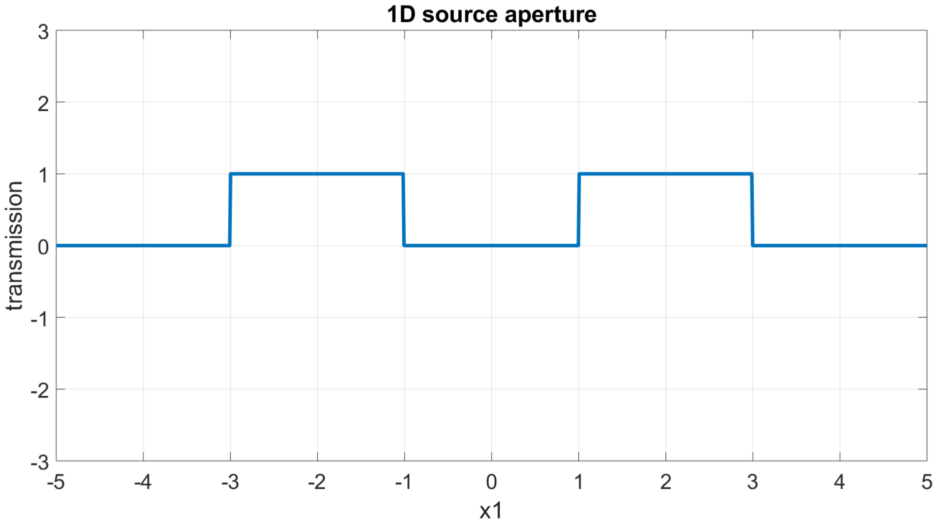

Figure 2: 1D representation source aperture along x_1.

Question Calculate the mask that you need to apply along the x_2 axis of the convolution processor in Figure 1 to achieve the field pattern shown in Figure 3 along the x_3 axis.

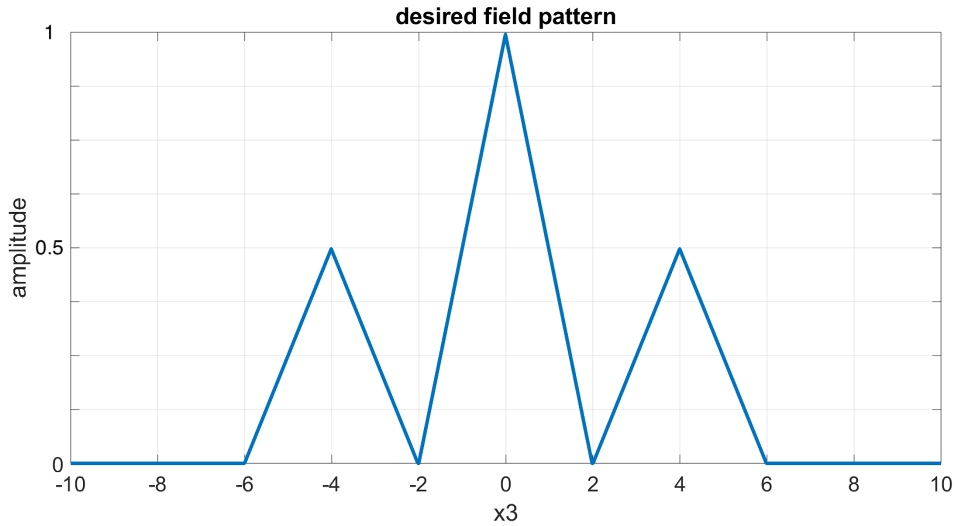

Figure 3: Desired field pattern along x_3.

Question Check your answer using the simulation tool: Optical Convolution Processor GUI, in the `exam` folder, open the `EXAM_aperture.m` as source. Attach a screenshot as your result.

1.2 Optical convolutional neuron network

A Convolutional Neural Network (CNN) typically initiates its architecture with a series of convolutional layers. Each of these layers engages in pattern matching through a set of adaptable visual filters (i.e., the convolutional kernels whose patterns can be trained to adapt the input data, helping the CNN extract feathers from input data). A CNN can be applied for object recognition in images and other AI tasks with structured data. To detect an object, an image must be convolved with a known reference image or a combination of image kernels. Such convolutions are, however, computationally intense on digital computers due to the large number of multiplications needed. In cases where instant detection is required, e.g., missile detection or real-time text-to-speech conversion, this can be too slow. An optical CNN solves this problem by performing an instant convolution, enabling passive conversion into the Fourier domain without power consumption or latency. A recent realization of an optical CNN can be seen in Figure 4.

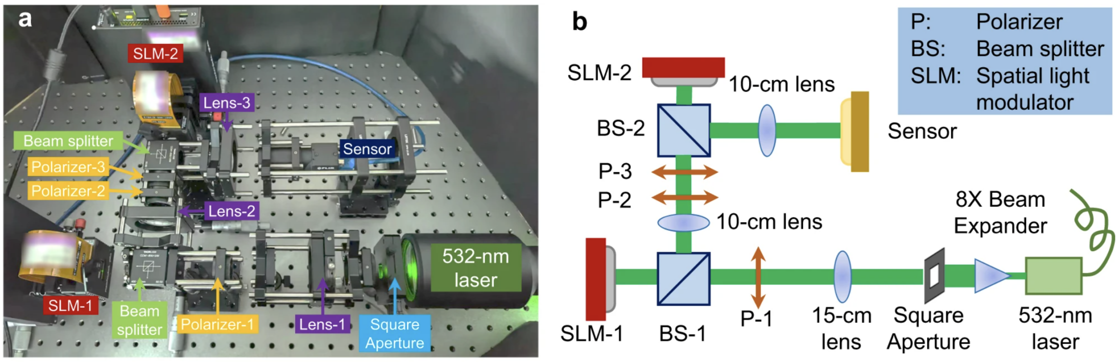

Figure 4: Recent realization of a physical optical CNN system in [Nat. Comm. (2023)]. (a.) Experimental setup. (b.) A schematic of the optical system.

Question Which kind of optical system do you think Figure 4 belongs to (you can ignore the two polarizers P-2 and P-3)? Explain in simple terms how the system in Figure 4 works. Where should we put the adaptable visual filters? What are the roles of SLM-1 and SLM-2, respectively?

Figure 5: An image from ImageNet dataset.

Question In this question, you will simulate based on the object in Figure 5 using the Optical Convolution Processor tool.

1. In the Optical Convolution Processor GUI, open the bitmap `test_8135.bmp` as source and try to choose a filter that sharpens the source field figure. Give a short explanation of what you choose and how this can be used for character detection. Also, add a screenshot.
2. Can you propose a method that iteratively extracts the features (e.g., eyes, head, legs...) from the original figure using an optical convolutional neuron network?

2 Waveguides (Lumerical)

In this exercise you will study the simulation of Evanescent Waveguide Couplers using the Lumerical FDE and EME solvers. This simulation is based on an example on Ansys Lumerical's website, which you can find here: https://optics.ansys.com/hc/en-us/articles/360042304694. We will consult this webpage from time to time. We will use the Lumerical file `waveguide_couplers_CAD_2023.lms`.

2.1 Study of the waveguide modes

Open the Lumerical file, where you will see two identical silicon waveguides on top of a SiO_2 substrate. The waveguides are 450nm wide and 220nm thick, which are standard dimensions for silicon photonic integrated circuits at 1550nm. In this exercise, we would like to look at the optical mode of these waveguides. Firstly, disable the right waveguide and make sure the FDE solver is set as active. Click 'Run' and calculate the modes of the left waveguide. What is the effective index of the fundamental TE mode? Please include a screenshot of your results for the mode calculation.

Figure 6: YZ view in Lumerical: With and without the waveguide on the right

2.2 Working principle of evanescent waveguide couplers

For the second exercise, please first read the section `FDE simulation and analytical formula` on the webpage until the paragraph with the formula for $L_{100\%}$.

1. In the simulation, re-enable the right waveguide and duplicate the mode calculation and calculate the index difference and $L_{100\%}$. Remember to enable the `mesh_gap` as well.

2. To verify the value we calculated, we can use the EME (EigenMode Expansion) solver. To do so, select the EME solver and 'set as active'. There are two ports within the EME solver. First, we need to select the fundamental TE modes for both waveguides. Go to the objects tree and find *Ports* under *EME*, right-click on *port_1* and choose *Edit object*. In the *Edit EME port* window, go to *EME port* and click *select mode(s)*, then you can calculate the modes (same as in FDE solver). Do the same for *port_2*. In this simulation, we set *port_1* as the input and *port_2* as the output. You don't need to provide any results for this part.

3. Run the simulation (it may take a few tens of seconds). After it is finished, go to the *EME analysis Window* and click *eme propagate*. Since we put an *EMEProfileMonitor* in our simulation, the module *eme propagate* allows to see how the light propagates. Right-click on the *field_coupling* and visualize the field profile. Provide a screenshot of the field profile. Is it in-line with your calculation in terms of the length for 100% coupling?

2.3 Evanescent coupling between silicon and InP waveguide

Above we studied the coupling between two identical waveguides but often we are interested in the coupling from a silicon waveguide to a waveguide made of another material. Here we would like to investigate the coupling from silicon to a InP waveguide. To do so, please disable the right silicon waveguide and enable the *right_InP* waveguide.

1. Enable the FDE solver again and check the effective index of the fundamental mode of the InP waveguide (don't forget to disable the right silicon waveguide). It is expected to be lower than silicon waveguide since the index of InP is lower than silicon. However, to maintain a 'perfect'coupling between two waveguides, we can adjust the width of the InP waveguide to let its effective index match with that of the silicon waveguide.

2. To be able to find the ideal width of InP waveguide, we need to sweep the width of the InP waveguide: In the *Optimizations and Sweeps* window, you can find a sweep with the name *InP_width_sweep*. Choose a start and stop value for the width of the InP waveguide. After setting up the sweep range, run the sweep and visualize the *n_eff* result. For which width has the InP waveguide the (approximately) same effective index as the silicon waveguide?

3. Now that we have both waveguides ready, please repeat exercise 2.2 on the current setup. You can keep the gap as 100 nm, or any reasonable values you think, as long as it matches with your calculation and simulation.