# Abstraction Models For Manufacturability Aware Silicon Photonics

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***Abstract*—Silicon photonic circuits are becoming more relevant in computing and AI applications. While it is feasible to simulate a single simple silicon photonic circuit with varying manufacturing defects, when trying to simulate larger circuits by combining multiple devices, current simulation programs fail due to how complex the transfer matrix equations become. Therefore, it is important to build abstraction models to help with simulating complex silicon photonic circuits and engineering software tools that will be able to run those abstraction models for analysis.**

***Index Terms*—Photonic, Coupler, Mach-Zehnder Interferometer (MZI), waveguides.**

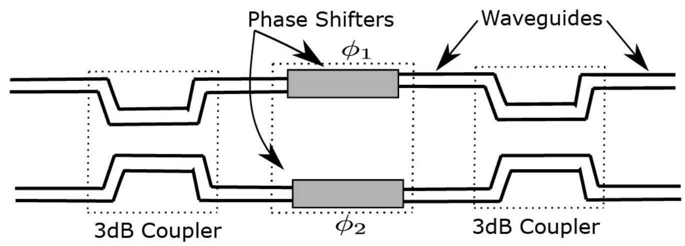


Fig. 1. Mach Zehnder interferometer

## I. Introduction

BASED on the work of Agnihotri et. al [1], we know that there is a way to simulate a single silicon photonic circuit with varying manufacturing defects. When trying to simulate larger, more, complex circuits by combining multiple silicon photonic devices, programs like Ansys Lumerical. Simulations fail due to how complex the transfer matrix equations become. This happens frequently when trying to model larger complex circuits that have an ever increasing number of photonic optical devices. Therefore, it is important to build abstraction models to help with simulating those complex silicon photonic circuits.

This proposal is to develop a computer program that will read in an interconnected complex circuit photonic and be able to simulate and synthesize them. I will need to first develop a data structure for the logic blocks in a circuit that are sinusoidal in nature to represent (matrix-based) and store the transfer functions that represent the devices. With the data structure abstraction in place, I can now represent the silicon photonic circuit in parts and build complex circuits through a netlist. This program will be built with the Python programing language. The toughest challenge will be finding the data structure design that is the most appropriate and can be integrated to read and create the circuits with the Computer Aided Design (CAD) tools within the project. One of the benefits of my program will be representing any known manufacturing defect of a silicon photonic circuit and run an algorithm to determine the best location within the circuit to do post-fabrication tuning (affecting reflective index). This will improve yield and reduce cost for silicon photonic circuits.

## II. History

Efforts are needed to develop defect models, tests, and validation procedures [1]. These silicon photonic devices are sensitive to changes in the manufacturing process and defects can occur in these devices at a very small scale. It can geometrically change the circuit design which will affect the refractive index of waveguides and potentially cause the circuit to malfunction [1].

Photonic silicon circuits can be modeled and represented through transfer matrix equations [1]. To do this, more parameters can be added to the optical circuits. The parameters can also be added to transfer matrices as phase modulators. By creating simulations of these photonic optical devices, you can represent manufacturing defects and simulate the behavior of the circuits as well as determine the best place to make fixes within the circuit.

In order to create these circuits, one can use optical switching devices, such as crossbar and Mach-Zehnder Interferometers (MZI) as shown in Fig. 1. With these designs, you can apply logic synthesis methodologies for large-scale optical circuits [2]. There have been other simulations created for single optical devices that have shown success in efficiently evaluating the circuit performance. This also allows us to change parameters which correlate to how the circuit performs, showing that this work can be extended to large scale photonic circuit simulations [3].

## III. Proposal

Building this python program that will be able to read silicon photonic circuits will help researchers simulate and verify how well these circuits work. Also by implementing debugging tools, researchers will be able to find focal points in the circuit that need to be modified to improve the output. This program will be very useful to many researchers by giving them the opportunity to test out their circuits and make design improvements. This program will be helpful with post-fabrication tuning when circuits have any manufacturing defects and in return will improve yield and reduce cost for silicon photonic circuits. This approach brings design-for-test to Si-photonics.

### A. *Project Tasks*

During this upcoming fall semester, I will need to develop the data structure that will represent the silicon photonic devices. These devices and their operations can be represented by a transfer matrix. Once this data structure is developed, I will move onto being able to read a file format containing multiple transfer matrices and composing a TM model for a complex si-photonic circuit. Once the program can read in silicon photonic circuit files and successfully build them and simulate them, I will want to start building the debugging tools. One tool that will be useful is implementing a topological sorting algorithm that will find any point within the circuit where weak output signals appear, i.e. weak controllability or observability. This will help the user know where to modify the circuit for better output results.

### B. Management and Communication

I plan to spend about 8 hours every week working on the project and I will be reporting to Professor Priyank Kalla. A planned out Schedule will be followed to ensure progress is made for this project.

### C. Milestones

*Milestone 1:* I plan to research and experiment with different data structures that I find best fitting to represent and hold photonic circuit's transfer matrix equations. This will also include choosing the best programming language that will allow me to create my program with the most efficiency possible. I also will be developing the file type needed to store these circuits that can also be read from by a program.

*Milestone 2:* During these next two weeks I will start creating Unified Modeling Language (UML) diagrams to help myself plan out the key features and implementations I want in my program. I will also be researching what types of programming libraries are out there that can help me create a more efficient program.

*Milestone 3:* I plan to begin the process of writing the code for my program and making sure I follow my UML design. I will break each part of my program into smaller parts so that I do not overwhelm myself by trying to write different parts of the program at the same time. Finishing the first small instance of my program which will be the data structure system and file read/write process.

*Milestone 4:* Implement the topological sorting algorithm to measure and find the best point to debug a faulty or inefficient optical device within the circuit. I know this part will take me a little longer because there will be a lot of trial and error to fine-tune the algorithm and there might be a chance that I need to use a completely different algorithm than I anticipated. For that reason, I am giving myself more time to make sure I can find a good efficient algorithm.

*Milestone 5:* I will move on to the final part of the program which will be to visually represent the circuit I read from a file to the user in the program through a graphical user interface (GUI). I want the GUI to show the design of the circuit and outline the different parts within the circuit so the user can see each optical device within it. I also want to display any important information about the circuit to the user based on the file it reads in.

*Milestone 6:* At this point, I should have everything I wanted to implement in my program completed and will be fixing up all my code and making improvements where they need to be to make sure my GUI looks clean and easy to understand. I will also be checking in with my mentoring professor and asking if there are any details or features that I should add. I will be making this period somewhat light so that I can focus on finishing my classes with good grades as well as beginning to study for my finals.

### D. Components to be Purchased/Built

This project will be built using python which is an open source programing language that I will use to build the program. A computer that has python installed on it and the VS Code application is the only current item on the bill of materials, which have been acquired. However, some books may need to be purchased to answer questions if my current available resources cannot answer them.

### E. Testing and Integration

Testing of my program will happen at different stages like testing the data structure, file system and reading circuit. I will follow my design plan starting with creating the data structure that will store the transfer matrices for each circuit. Once I can store the circuit, I will move onto being able to read a file type that contains multiple transfer matrices. After, I will put these two pieces together to be able to represent the circuit and simulate the output. Finally, I will have to test different topological algorithms that will help with locating weak output points in the circuit.

By breaking the program into these parts, I can do incremental testing to verify each step in the building process. Once I know that the current step has been tested thoroughly, I can begin putting the parts together and testing the build as a whole.

### F. Risk Assessment

The main risk for this project will be the data structure that I create to represent and hold and store the transfer matrix. This data structure is the foundational block to my program because it will be the main entry point for any simulation or debugging. Making the data structure the main priority will allow me to research different options while testing different structures to find one that works appropriately.

Other medium risks are simulating the circuits and the debugging tool because both will be based on an algorithm that I implement. I need to make sure the algorithms I choose work with the transfer matrices. Currently, there is a Ph.D student working with under the same Professor as me who has had success with simulating a single device circuit. I will make sure to ask this student for help if I begin struggling with the simulation since they already have experience.

### G. Deliverables

The final deliverable will be a fully functional python program that can simulate and debug complex silicone photonic circuits. This program should be able to show the user where there may be some rework needed within their circuit or even show how to improve any manufactured defects within a circuit.

## IV. Summary

## References

[1] A. Pratishtha, P. Kalla, and S. Blair, ”Transfer-matrix abstraction to analyze the effect of manufacturing variations in silicon photonic circuit,” (2022)

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