Simulating a Mach-Zehnder Silicon Photonic Switch

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UCSB

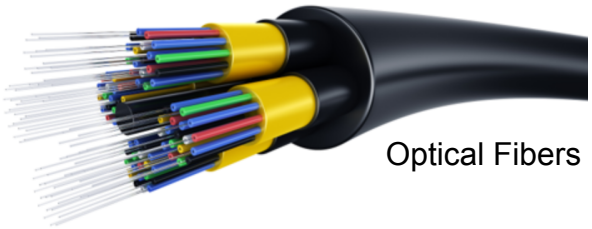
AIM photonics
AMERICAN INSTITUTE for MANUFACTURING INTEGRATED PHOTONICS

CSEP

Photonics and Electronics: What's the Difference?

Photonics

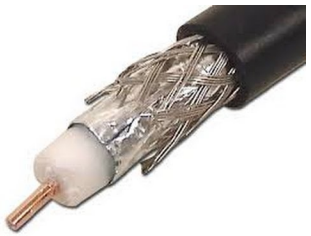
- Study and application of light



Optical Fibers

Electronics

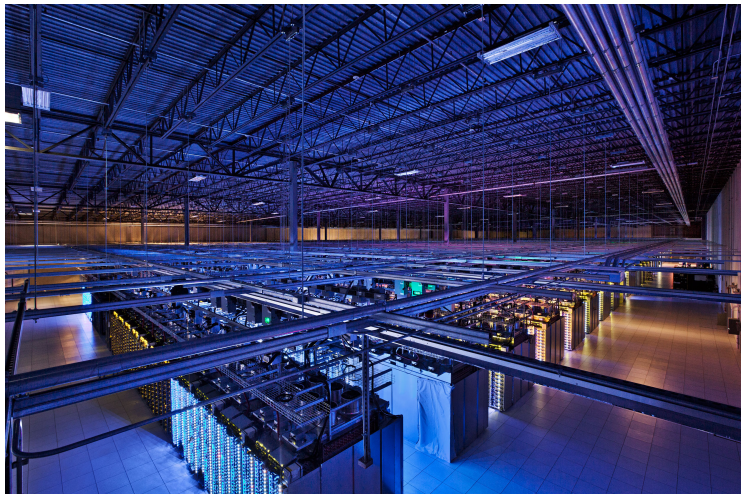
- Study of flow and control of electricity



Coaxial Copper Cable

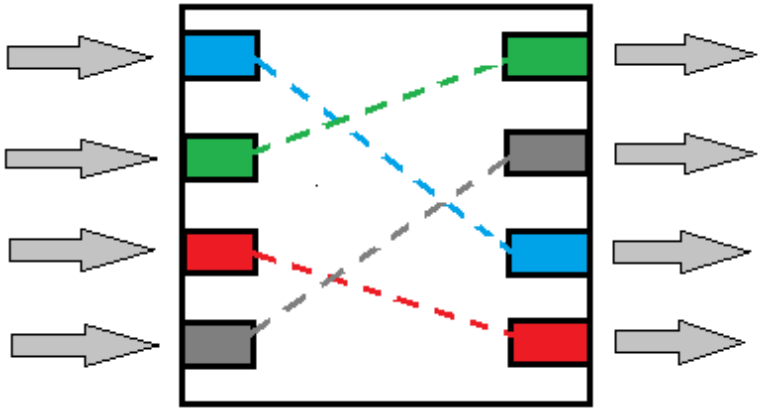
✔	Speed	
✔	Bandwidth	
✔	Low Attenuation	
✔	Immunity	
✔	Durability	
✔	Security	

Managing Growth in Data Centers



- Global data traffic expected to increase from 6.2 EB (10^{18} bytes) per month in 2016 to 30.6 EB per month in 2020
- As a result, data centers continue growing in size and complexity

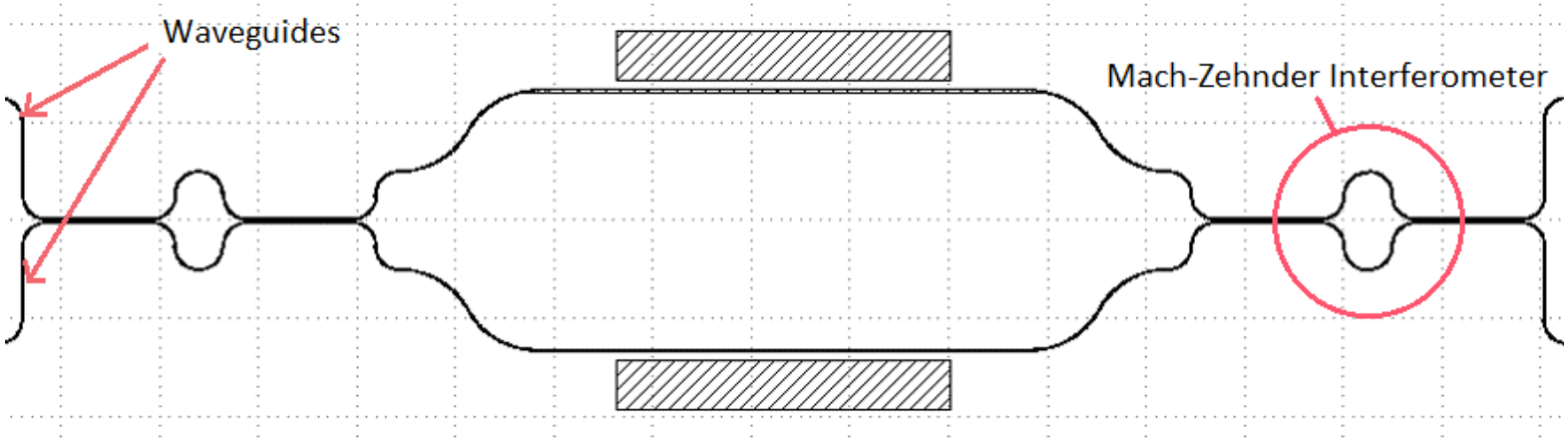
- Photonic Switch: Reroutes information transmitted as light of a certain wavelength
- Used for optical networking



4 x 4 Switch

Simulating a Mach-Zehnder Photonic Switch: Research Goals

1. Determine bandwidth – Range of frequencies that can be rerouted
2. Simulate loss
3. Optimize switch – Increase efficiency, reduce crosstalk and footprint



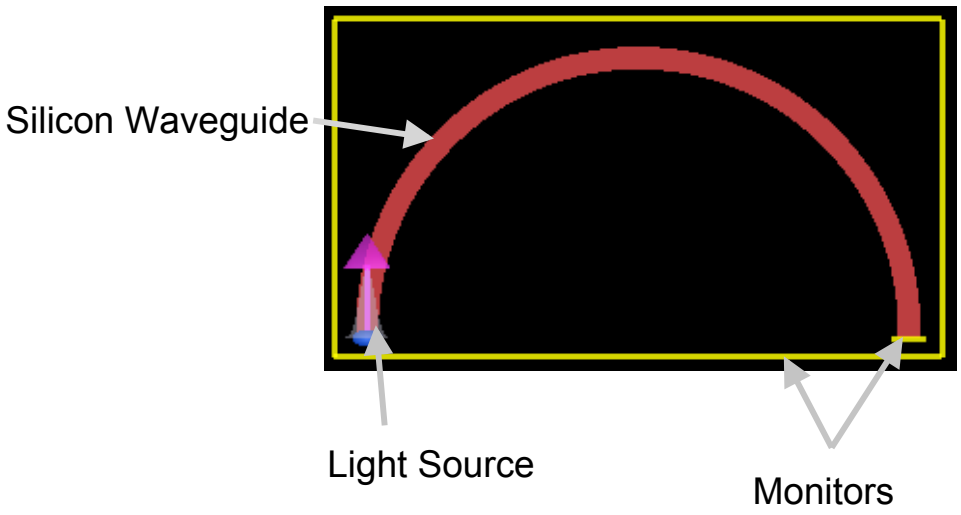
Layout of a Mach-Zehnder Block: A Portion of the Photonic Switch

Simulating a Mach-Zehnder Switch: Research Methods

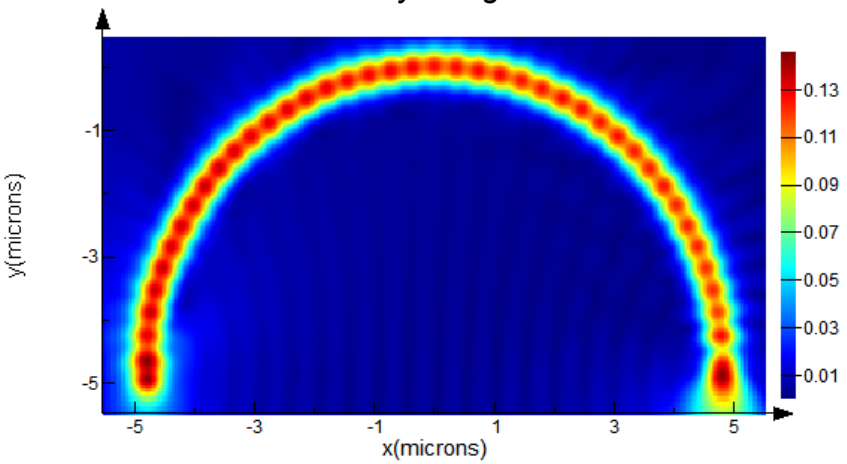
Performance Check | Calculate Parameters | Determine Bandwidth

Basic test for performance of switch components at 1310 nm using Lumerical FDTD (Maxwell solver)

A Simple U Bend



Intensity along U Bend



Simulating a Mach-Zehnder Switch: Research Methods

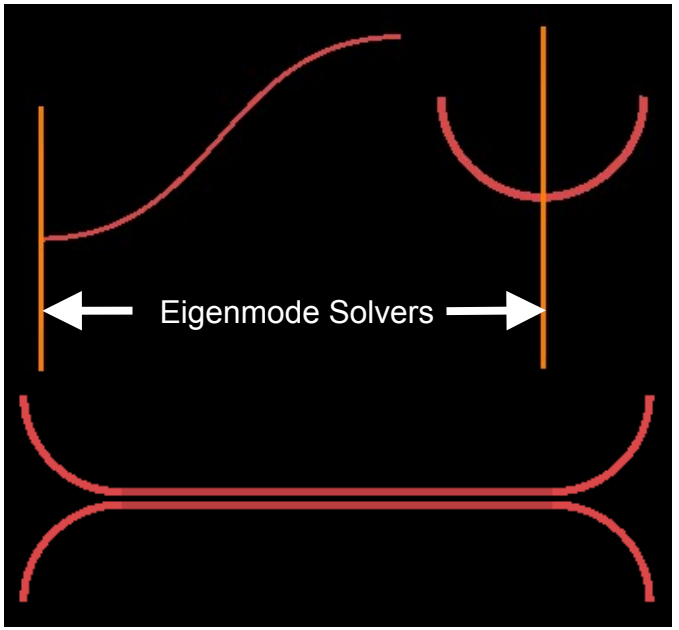
Performance Checks | **Calculate Parameters** | Determine Bandwidth

Determine different aspects of waveguides in Lumerical MODE using modal and frequency analysis

- Effective refractive index (n_{eff})
- Group index (n_g)
- Loss
- Dispersion

Components to test:

- Directional couplers
- 90 degree bends
- S bends
- Straight waveguides

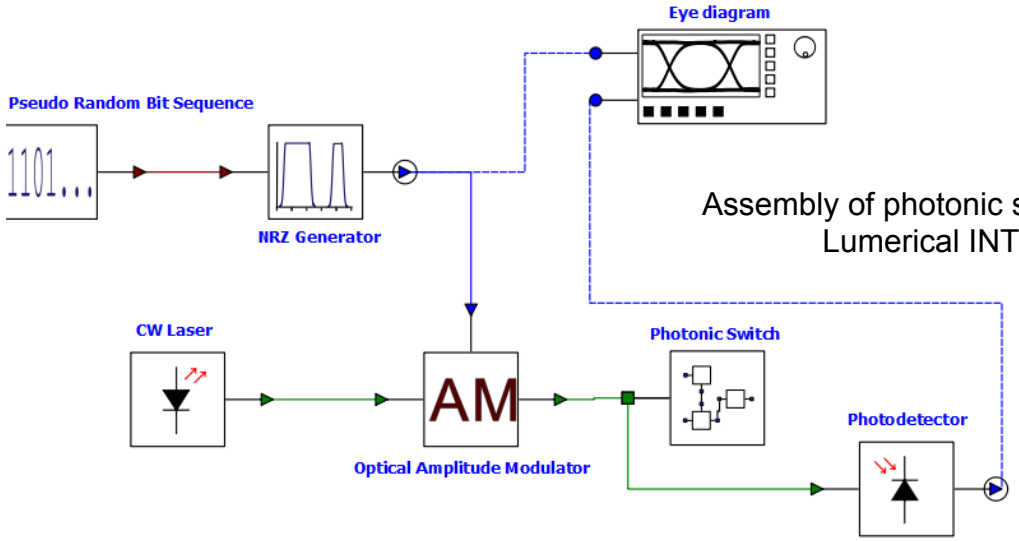


Top left to right: S Bend, U Bend
Bottom: Directional Couplers

Simulating a Mach-Zehnder Switch: Research Methods

Performance Checks	Calculate Parameters	**Determine Bandwidth**

- Switch is assembled in Lumerical INTERCONNECT using parameters from Step 2
- BER (Bit error rate) testing and Eye Diagrams used to analyze switch performance at various frequencies
- Bandwidth determined using cutoff threshold of at most 10^{-9} BER.



Assembly of photonic switch and test setup in Lumerical INTERCONNECT

Results: Waveguide Parameters

Refractive Index:

- Silicon (Si): 3.44
- Silicon Dioxide/Silica (SiO_2): 1.43

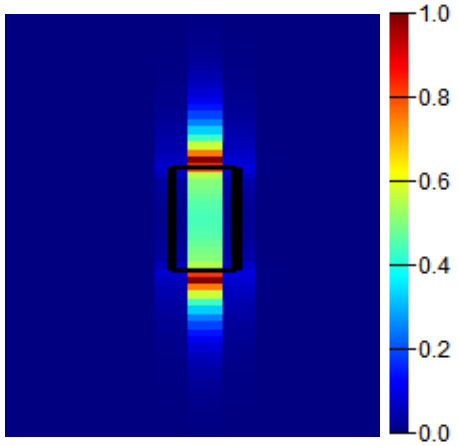
Effective Index (ratio of propagation constant of light in waveguide to free space propagation constant):

- determined to be ~ 2.22 for waveguides

Loss:

- Straight waveguides: 55.92 dB/cm
- 90 degree bends: 0.028 dB

Overall, calculated parameters are most likely accurate



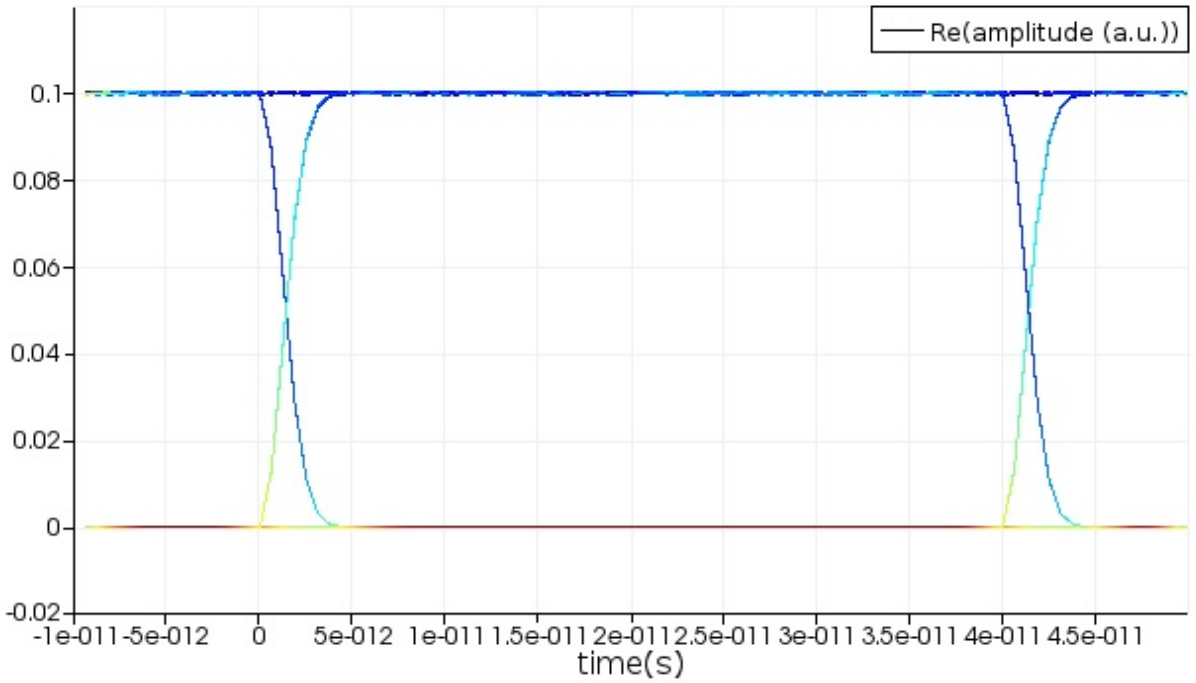
Electric Field Intensity along a U-Bend

Ideal Case: BER and Waveguide Bandwidth

Ideal Case scenario:

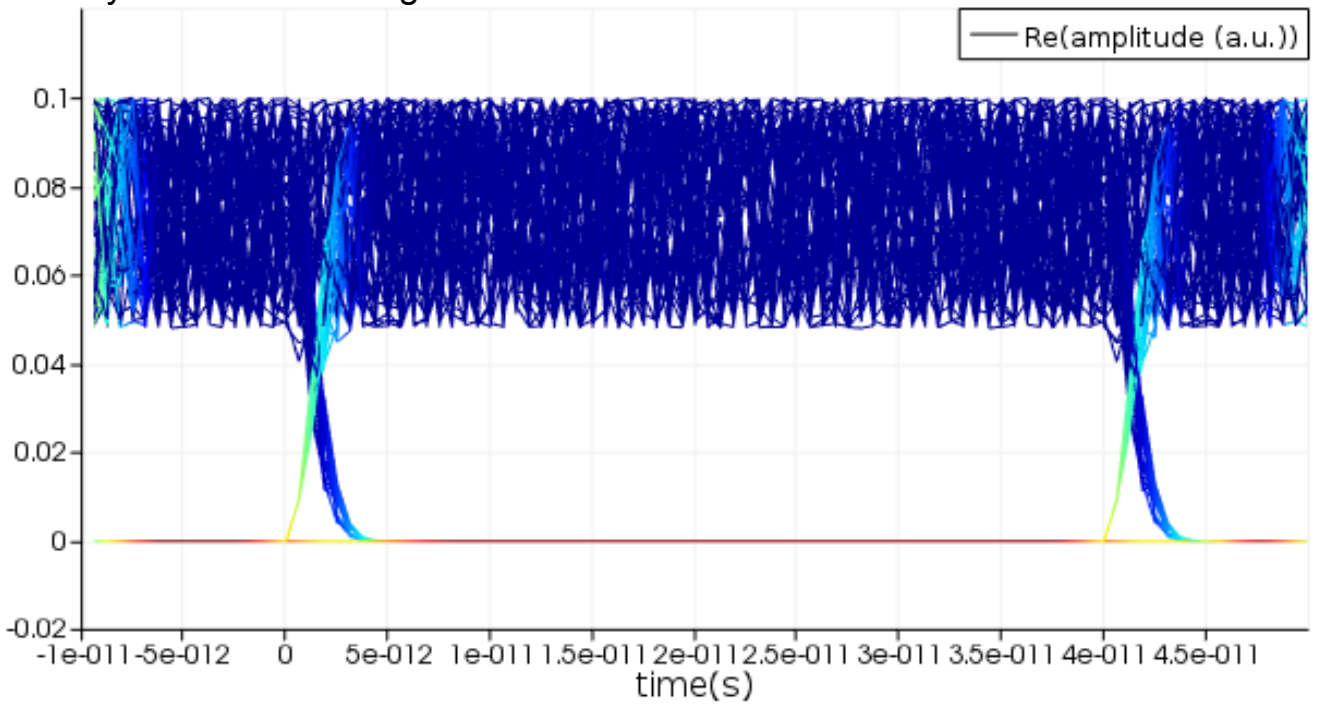
- BER at 1310 nm much less than 10^{-9}
- Clean and jitter-free eye diagram

Eye Diagram: Ideal Case



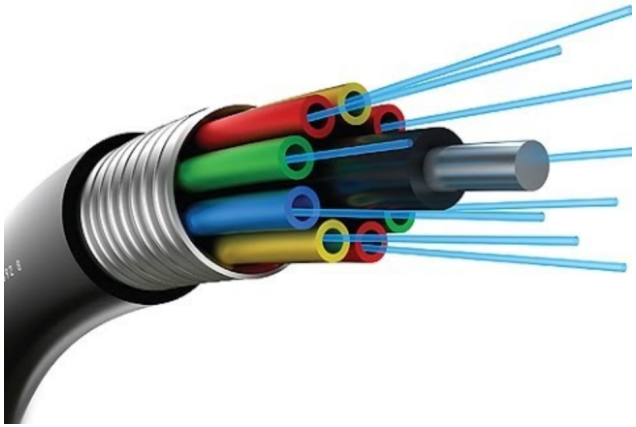
Results: BER and Waveguide Bandwidth

BER: 0.024, which is incredibly high
Testing parameters may need to be changed



Future Goals: Optimizing Mach-Zehnder Switch

- Determining bandwidth of switch will help develop test cases for actual chip
- Find ways to increase efficiency and reduce crosstalk of switch
- Photonics is the future



"The 21st century will depend as much on photonics as the 20th century depended on electronics" – IYL2015

References

Berney, "How fiber optics work," in YouTube, 2014. [Online]. Available: https://www.youtube.com/watch?v=9VmA2S2XiCo. Accessed: Jul. 15, 2016.

Chrostowski and M. Hochberg, *Silicon Photonics Design: From Devices to Systems*. 2015.

C. Zhou, "A server room in Council Bluffs, Iowa," 2012. [Online]. Available: http://www.wired.com/2012/10/ff-inside-google-data-center/. Accessed: Jul. 29, 2016.

G. P. Agrawal, *Fiber-optic communication systems*, 4th ed. New York: Wiley-Blackwell (an imprint of John Wiley & Sons Ltd), 2010.

N. Dupuis *et al.*, "Design and Fabrication of Low-Insertion-Loss and Low-Crosstalk Broadband 2×2 Mach–Zehnder Silicon Photonic Switches," *Journal of Lightwave Technology*, vol. 33, no. 17, pp. 3597–3606, Sep. 2015.

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