Multi-Transverse-Mode Optical Processors: Towards On-chip Programming and Calibration

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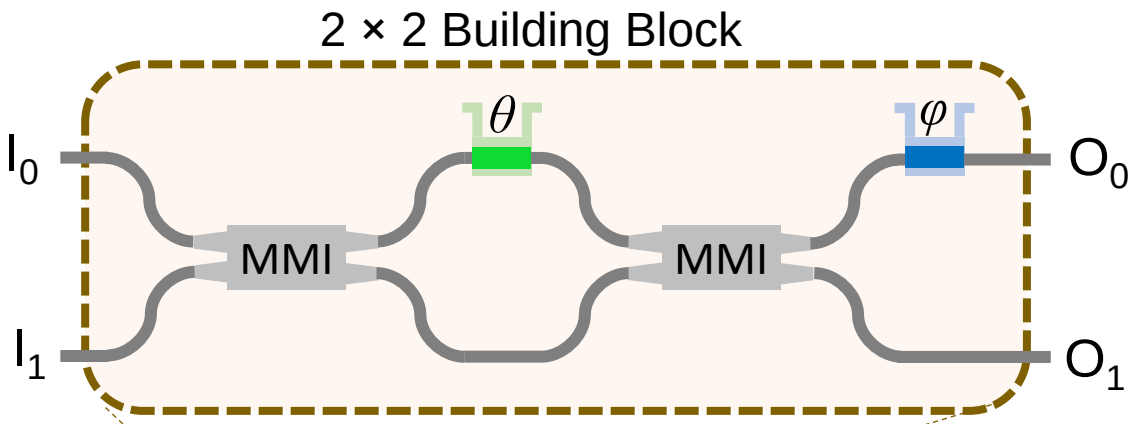
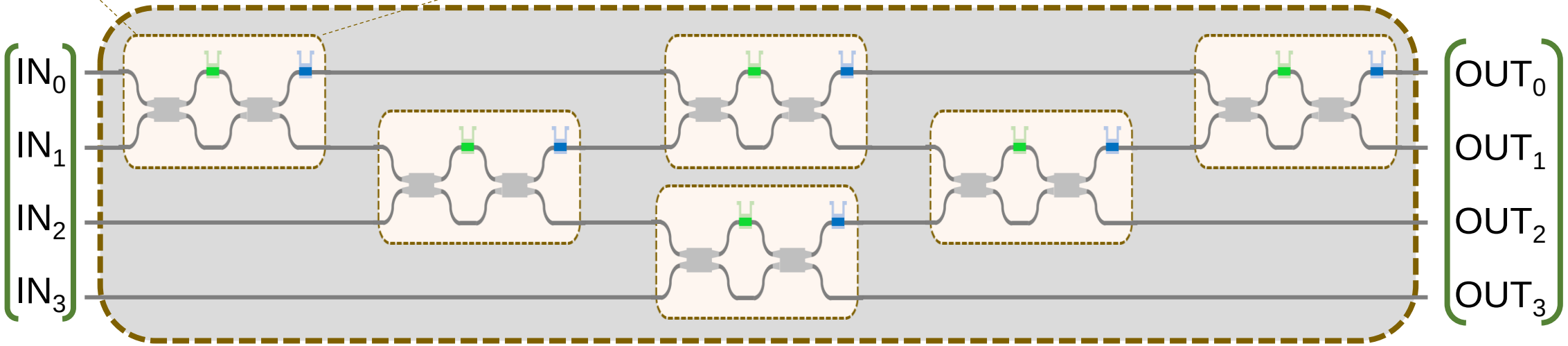
Presentation Outline

- Review on programmable optical processors
- Challenges in calibration and programming of conventional optical processors
- Proposing Multi-transverse-mode optical processor (MTMOP) to address the calibration issues
- Experimental validation of MTMOP
- Conclusion

Programmable optical processors – building block

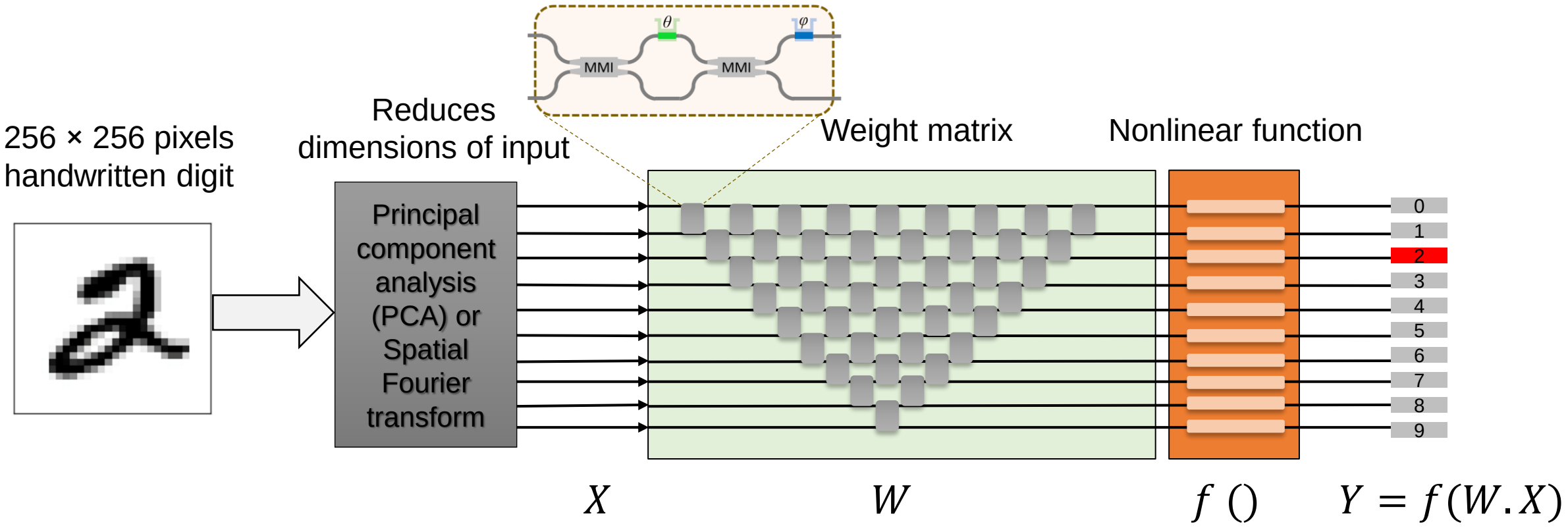


$$\begin{bmatrix} E_{O_1} \\ E_{O_2} \end{bmatrix} = je^{j(\theta/2)} \begin{bmatrix} e^{j\phi}\sin(\theta/2) & e^{j\phi}\cos(\theta/2) \\ \cos(\theta/2) & -\sin(\theta/2) \end{bmatrix} \begin{bmatrix} E_{I_1} \\ E_{I_2} \end{bmatrix}$$



Programmable Optical Processor

Programmable optical processors for ML

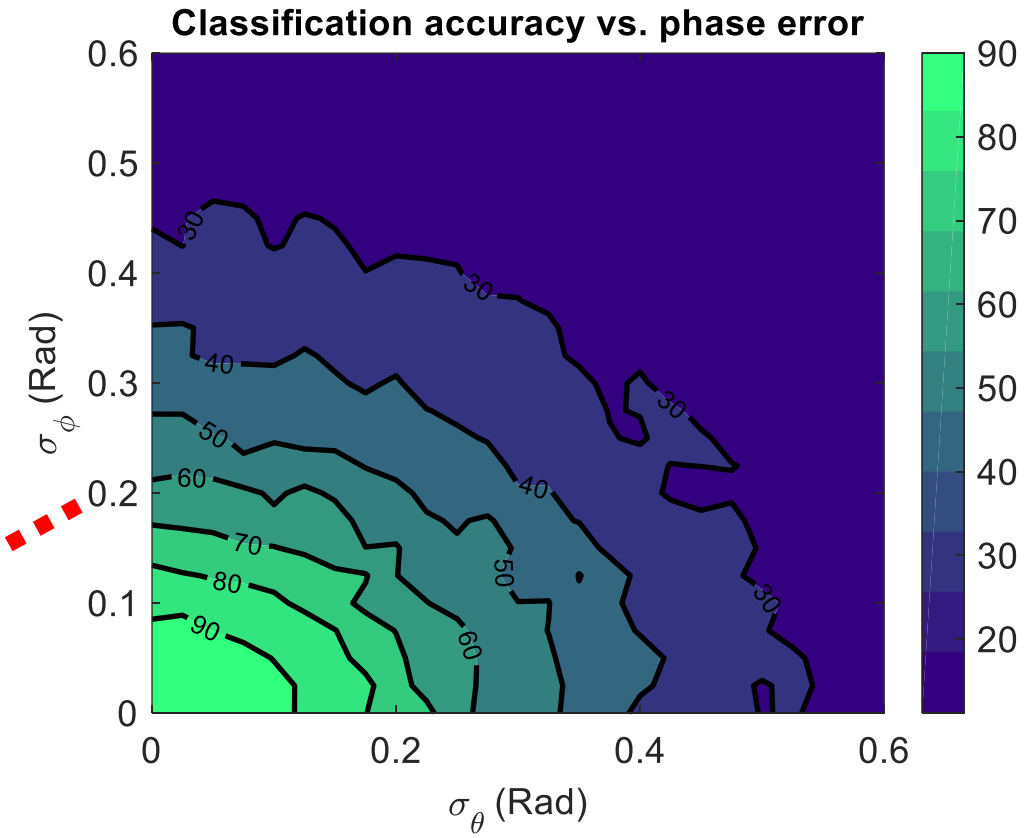


Phase error, calibration, and programming

How precise should the phase setting be?

- Phase shifter inaccuracy caused by various effects, mainly thermal crosstalk and electro-optic precision (bias voltage accuracy and stability)
- Accuracy drops from 90% down to 60 for phase variance of less than 0.1 rad to approximately 0.2 rad.
- A 100 um TiN-based TOPS with a 2.7K temperature fluctuation lead to an accuracy drop to 60%
- This is equivalent to approximately 30 mV of voltage deviation

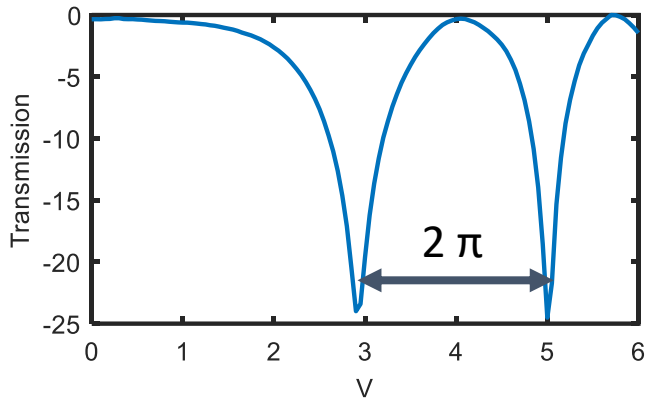
2.7 K of temperature error
or 30 mV voltage deviation



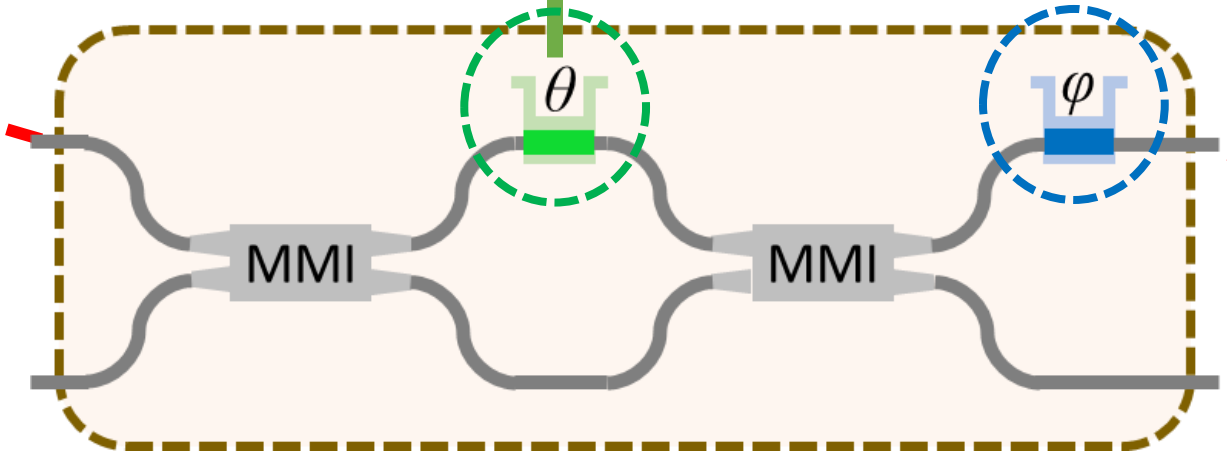
Calibration and programming: optical phase measurement

Laser

Voltage supply



Optical power meter

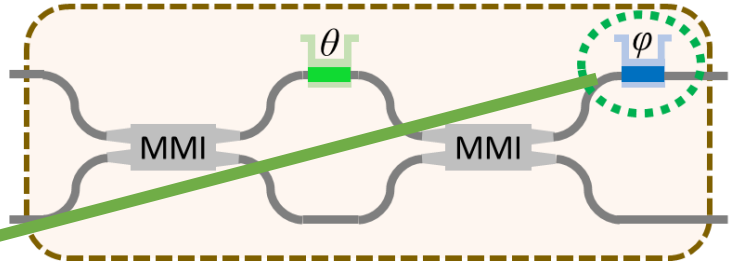


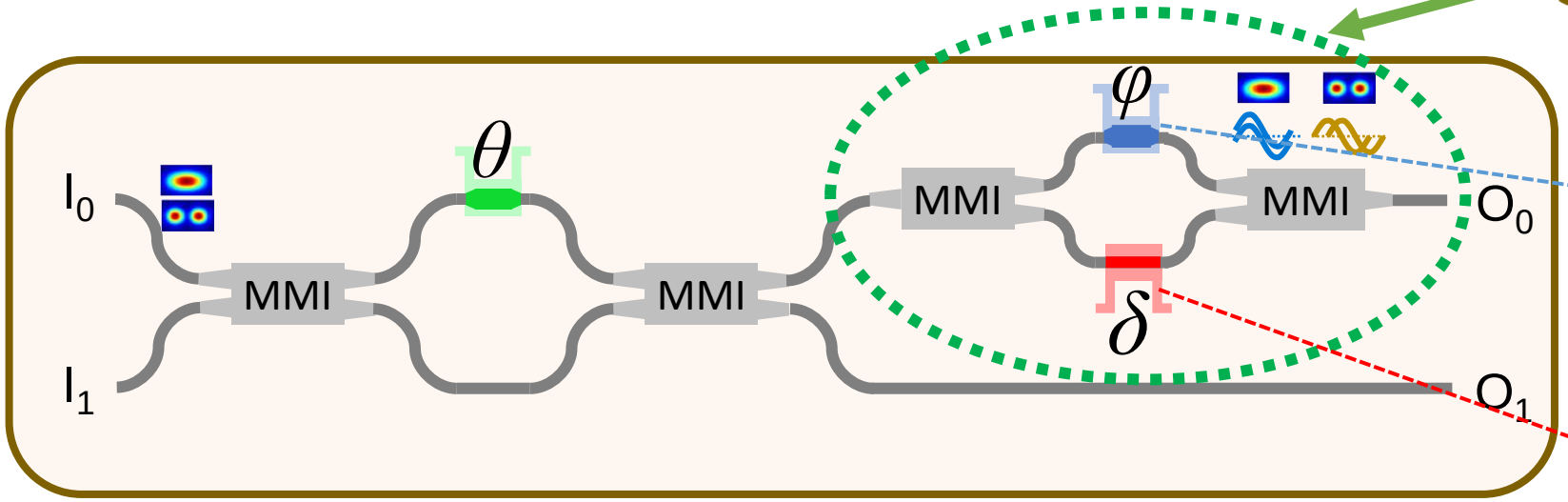
Optical Vector Analyzer

Proposed approach: Monitoring phase shift using MTMOP

- Using two transverse electric (TE) modes
- TE0 carries the main signal
- TE1 for calibration and programming purposes
- MTMOP building block converts TE0 phase shift into TE1 power

Conventional 2×2 Building Block





Multi-transverse mode optical processor (MTMOP) 2×2 Building Block

Mode insensitive phase shifter

$$\frac{dn_{eff}(TE0)}{dT} = \frac{dn_{eff}(TE1)}{dT}$$

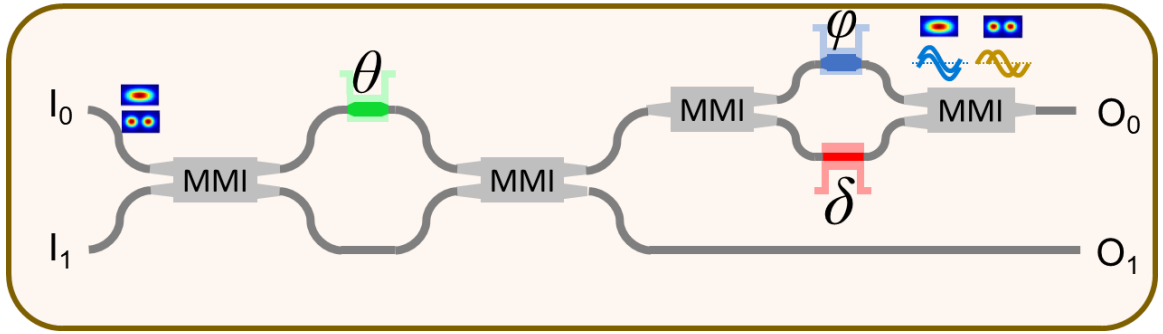
Width= 4 μm

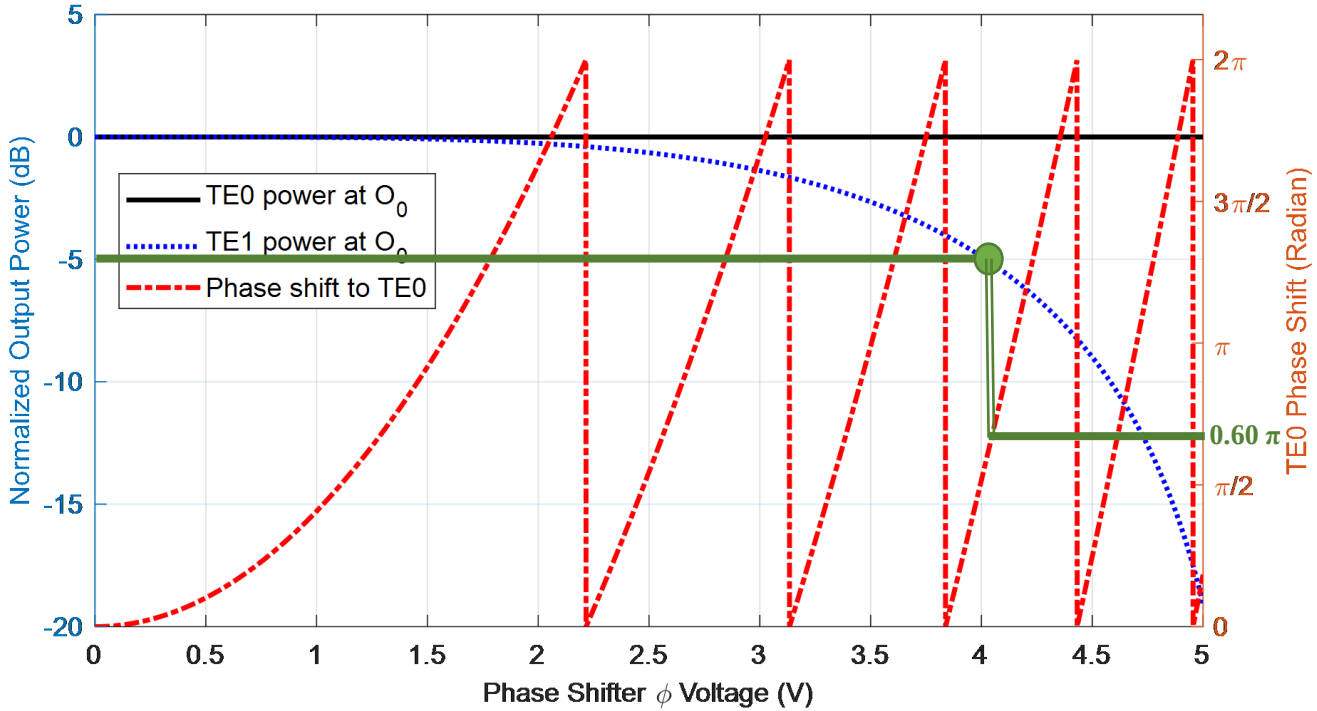
Mode sensitive phase shifter

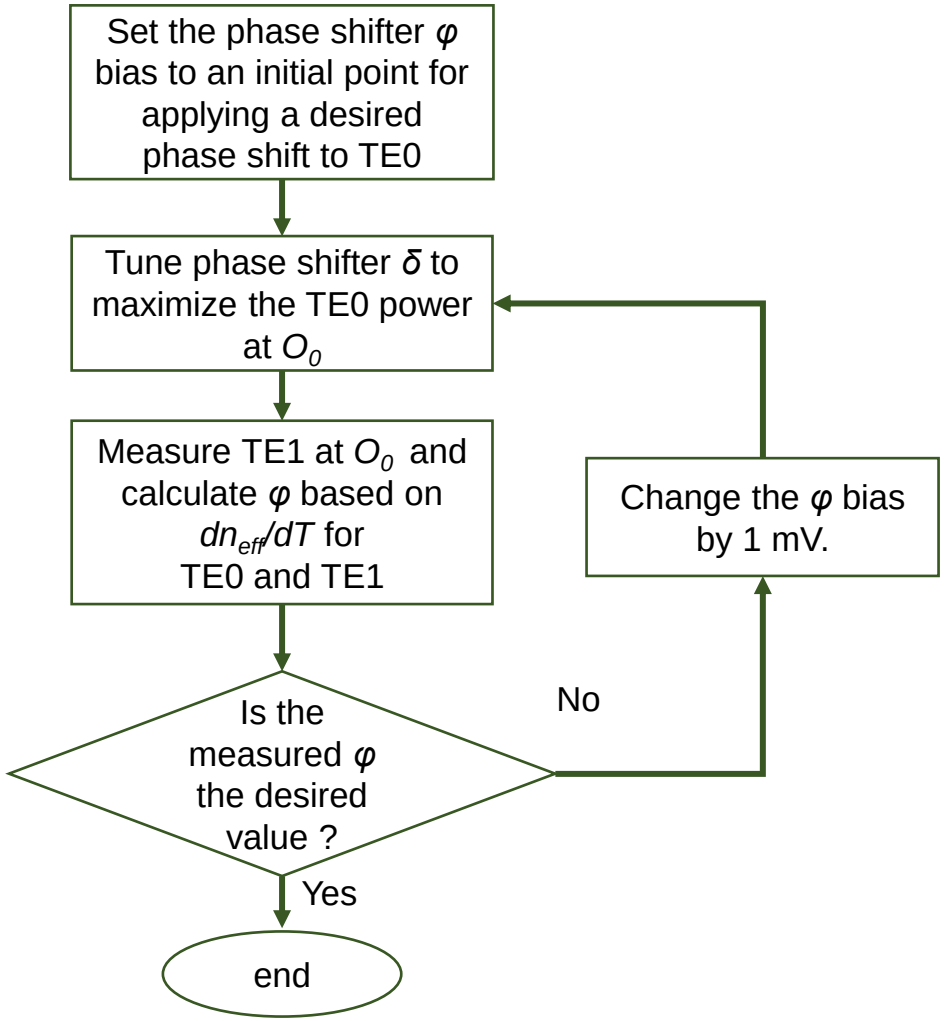
$$\frac{dn_{eff}(TE0)}{dT} \neq \frac{dn_{eff}(TE1)}{dT}$$

Width= 0.96 μm

MTMOP principles of operation



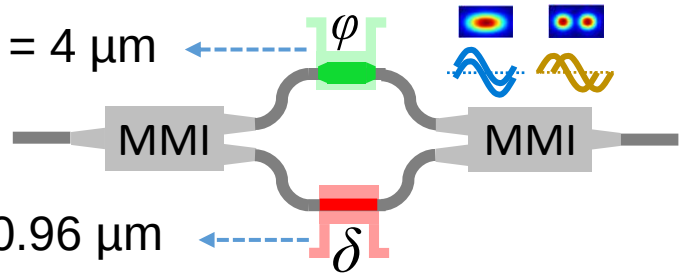




Experimental validation – Preliminary results

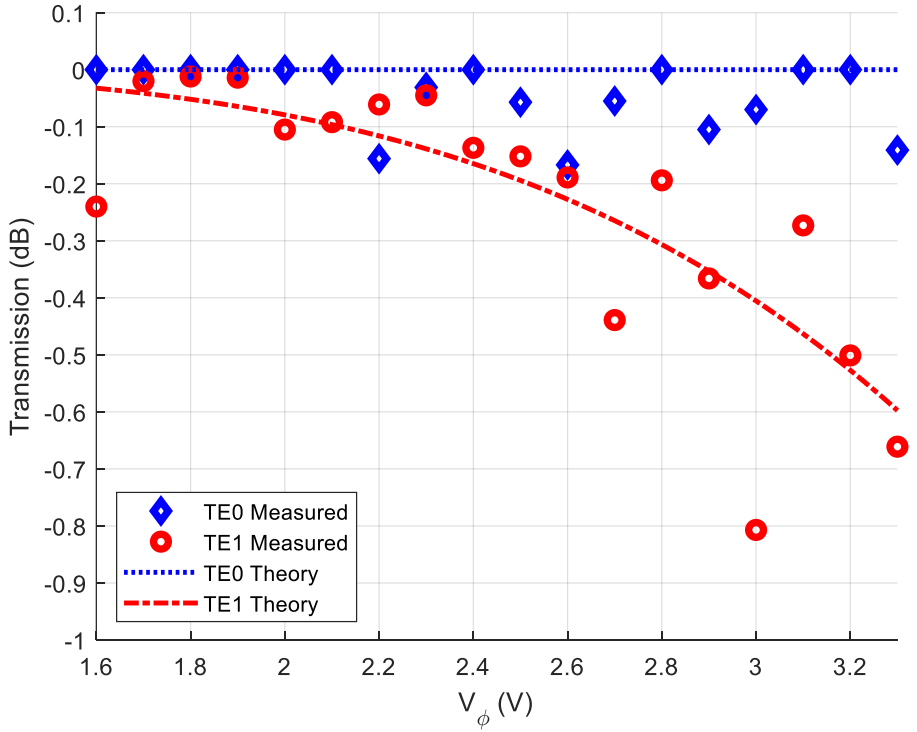
Mode insensitive - width = 4 µm

Mode sensitive - width = 0.96 µm

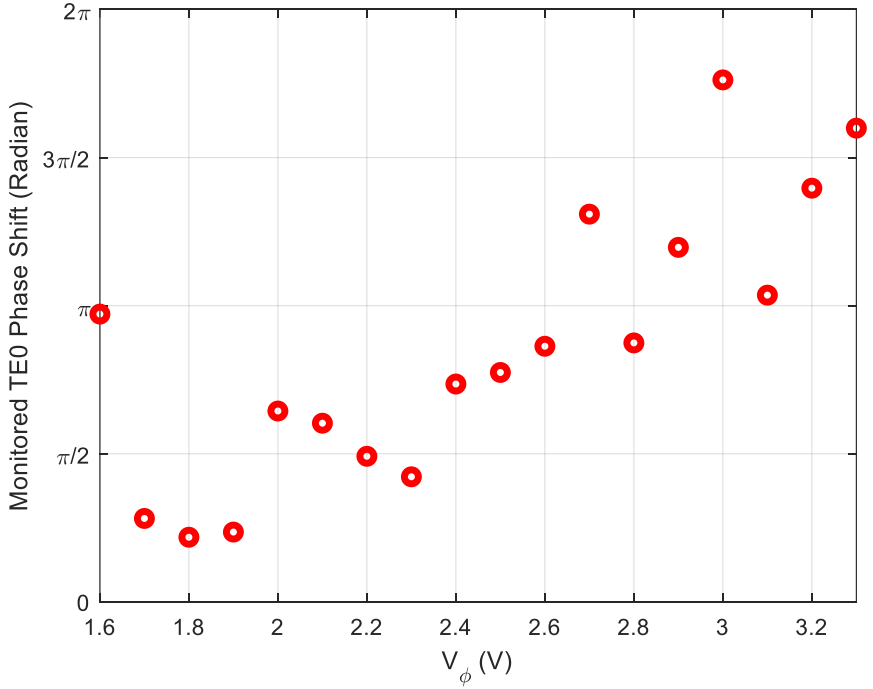


Thermo-optic coefficient, dneff/dT

	TE0	TE1
φ	1.74	1.74
δ	1.80	1.96



Transmission TE0 and TE1 modes



Extracted TE0 phase shift
from measured TE1 transmission

Conclusion and future work

Conclusion

- Proposing the MTMOP: A Multi-Transverse-Mode Optical Processor
- The MTMOP design addresses calibration challenges of optical processors.
- The MTMOP enables an embedded calibration and programming of the optical processor
- Experimentally validated an MTMOP prototype on SiPh.

Future work

- Increase the mode sensitivity of mode-sensitive phase shifter.

Slides are available at: http://rahbardar.research.mcgill.ca/
More information on MTMOP:
Kaveh Mojaver and Odile Liboiron-Ladouceur, “On-chip Optical Phase Monitoring in Multi-Transverse-Mode Integrated Silicon-based Optical Processors,” arXiv:2205.10414v1, May 2022

Thank you!