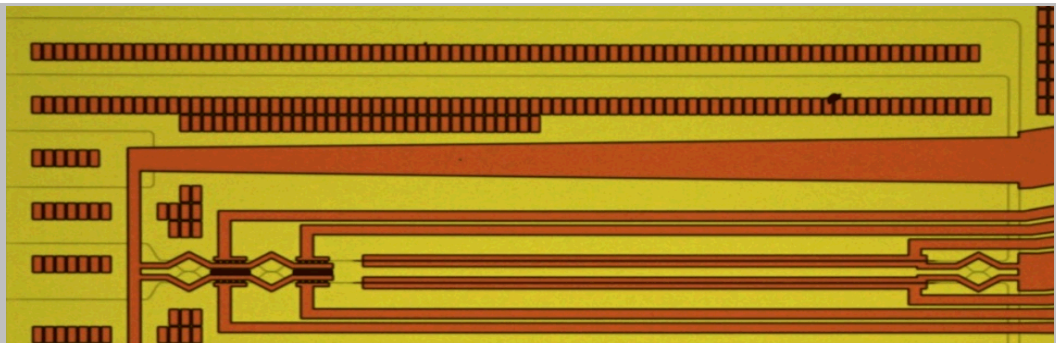
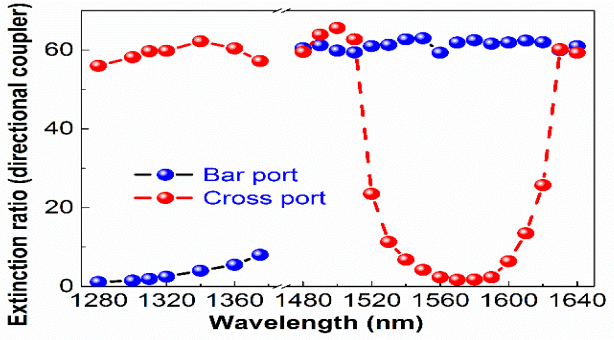
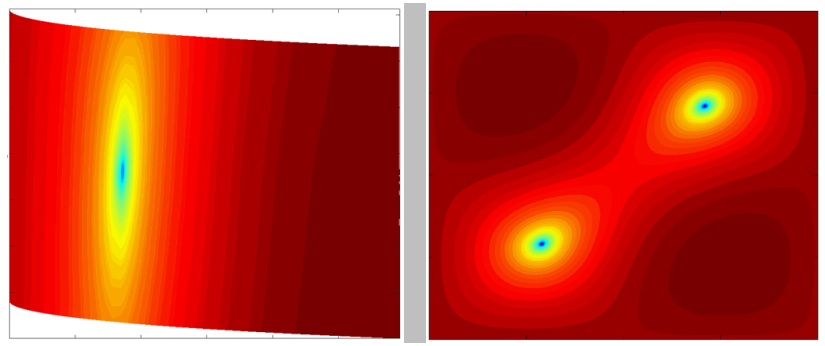
SAND2017-5486C







Ultrahigh extinction on-chip amplitude modulators with broadband operation

Sheng Liu, Hong Cai, Christopher T. DeRose, Paul Davids, Andrew Pomerene, Andrew L. Starbuck, Douglas C. Trotter, Junji Urayama, Ryan Camacho, Anthony Lentine

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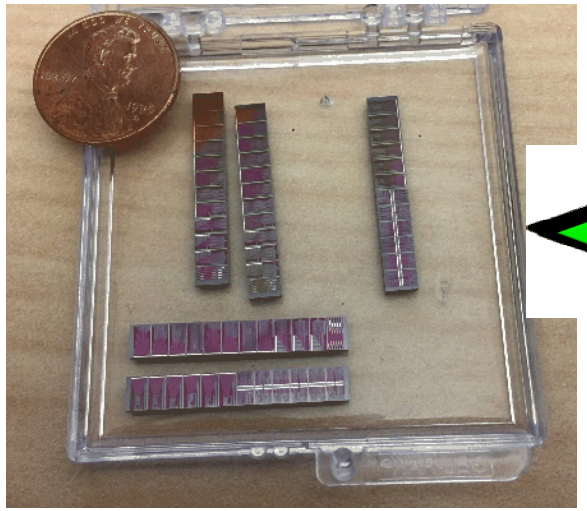
Integrated silicon photonics

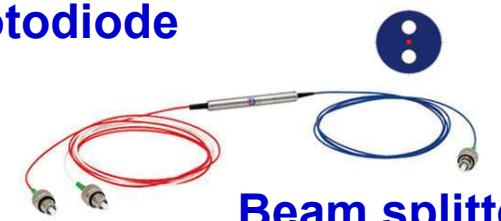
- **Scalable CMOS compatible** – electronic fabrication readily be used
- **Low cost**: Si, batch fabrication
- **Ultra-compact**: small size, light weight, more reliable, low power consumption (fj/bit)
- **Applications**: data center, short distance communication, Telecom/Datacom, High performance computer, self-driving cars (~$1 billion market in 2025)



Phase modulator

Amplitude modulator

Balanced photodiode



Beam splitter

Silicon photonics bottleneck-stringent fab requirement

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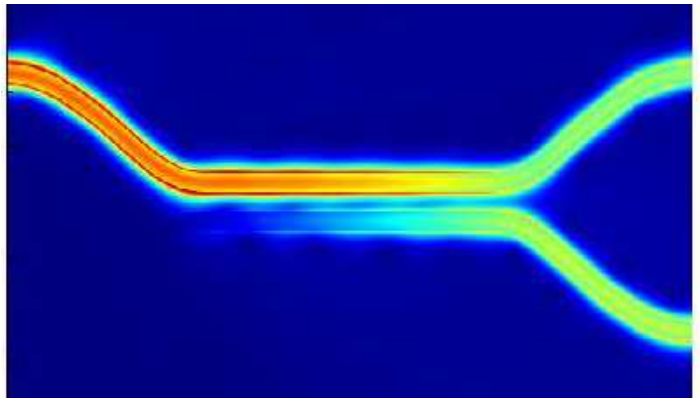
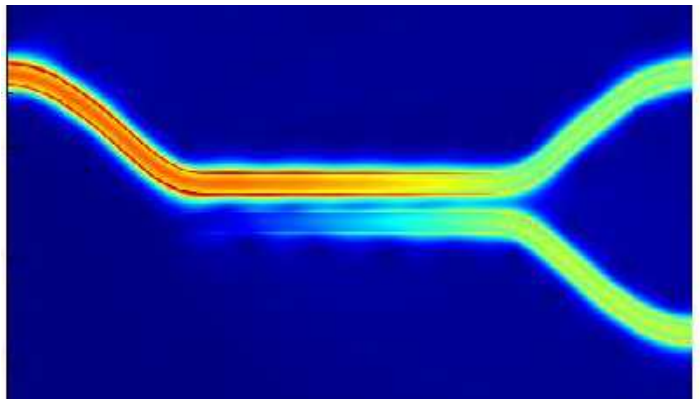
Require tight fabrication tolerance < 10 nm: Si wafer's Si active layer has more than ±5% (> 10nm) variation

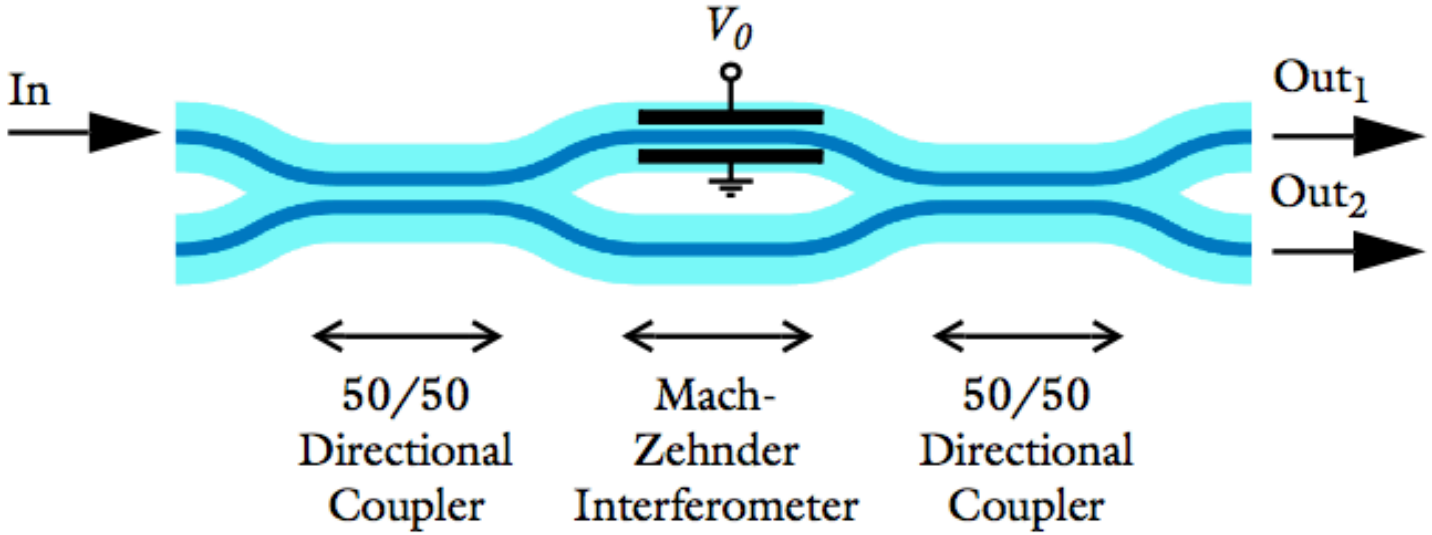
230nm thick, 400 nm width, 320 nm gap



240nm thick, 390 nm width, 340 nm gap



Conventional Mach-Zehnder Interferometer based AM

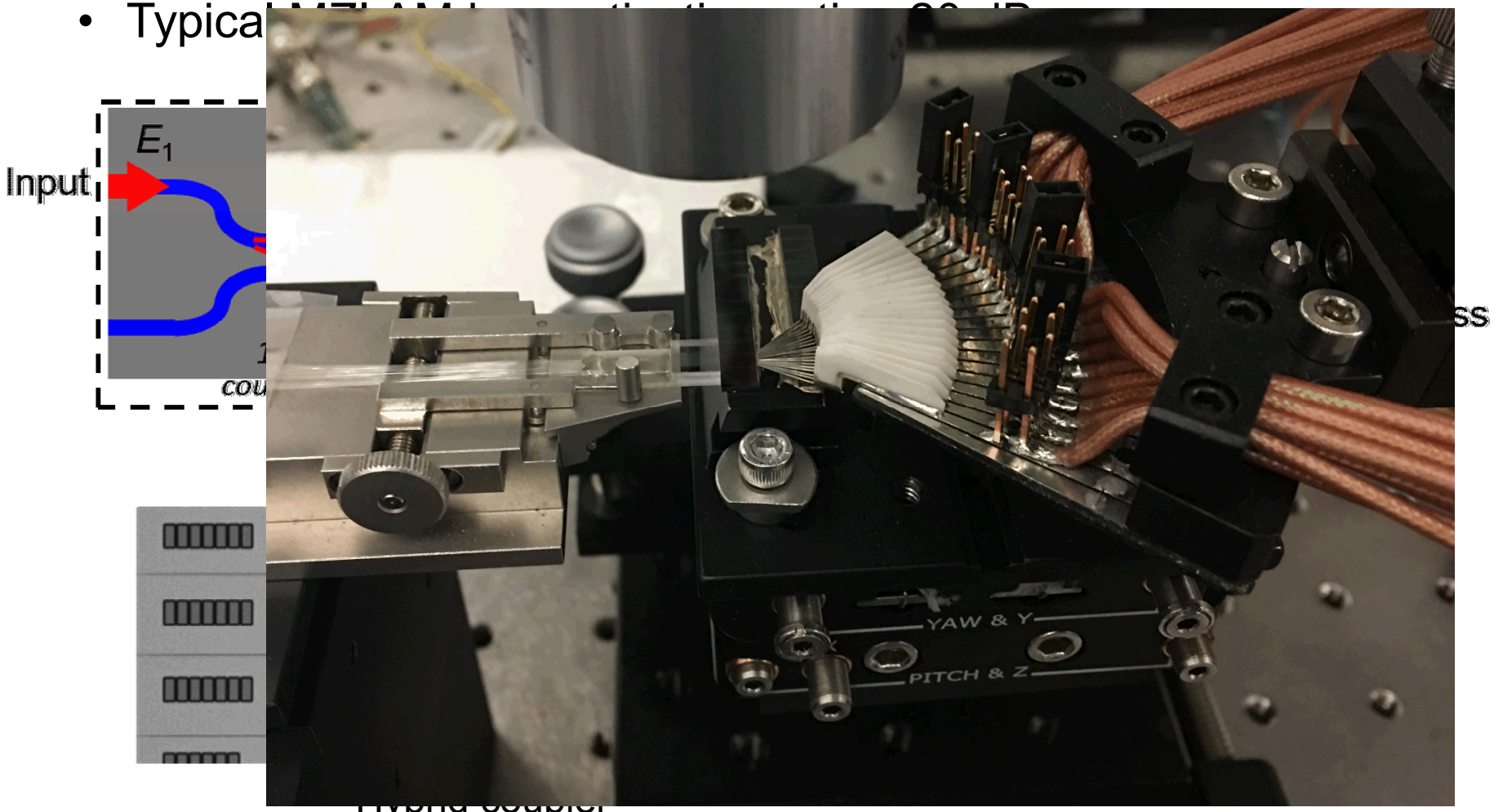


Directional/hybrid couplers are narrow bandwidth operation

- **Fabrication-tolerant design**
- **Broadband operation**

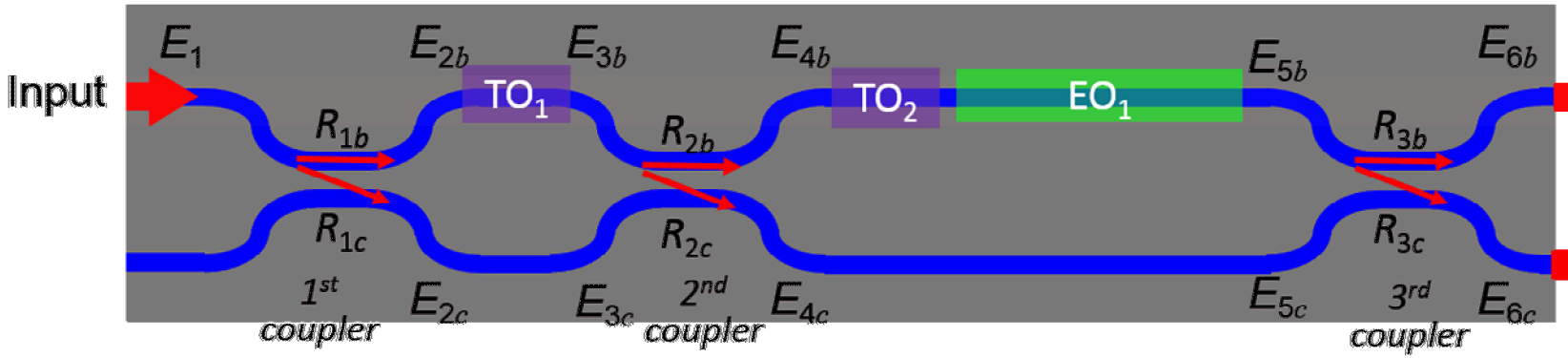
High extinction ratio AM—cascaded MZI (CMZI)

- >30 dB extinction ratio (low crosstalk) AM is needed,
- Typica



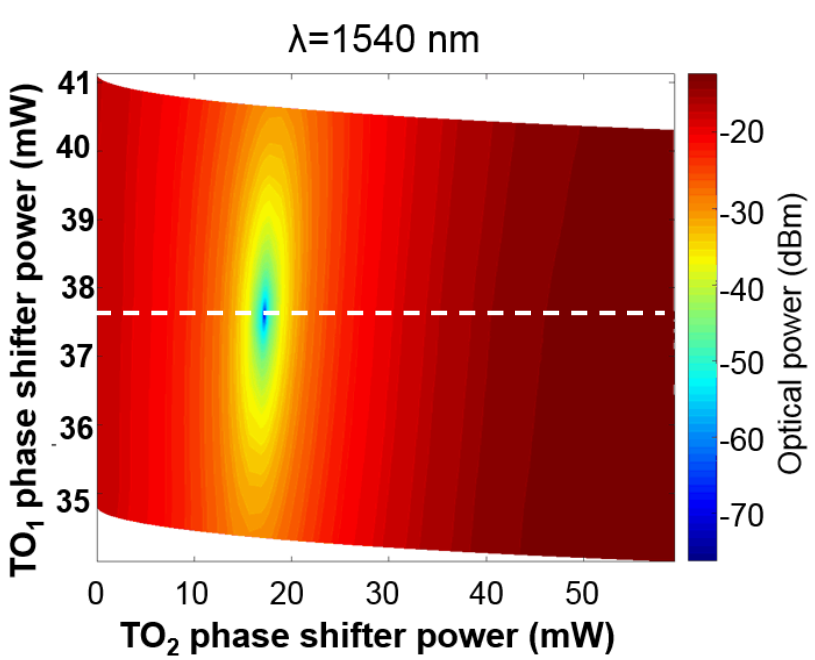
- 3 couplers (2+1)
- "arbitrary" power splitting at E_{4b} & E_{4c}
- TO, EO phase shifters

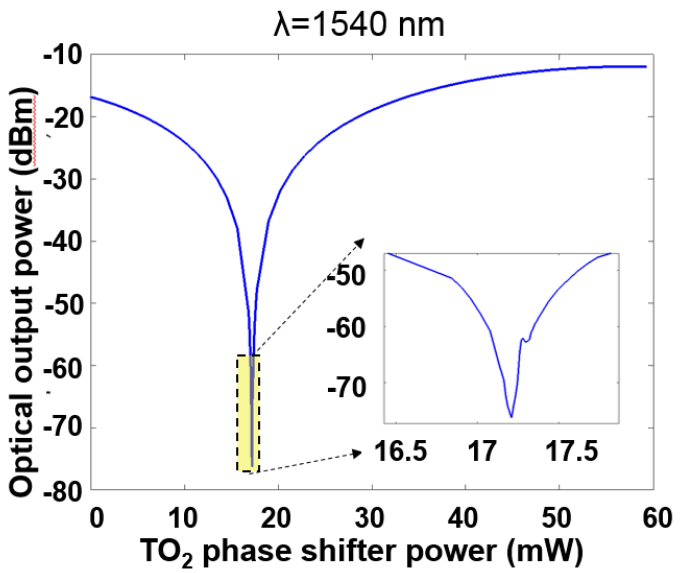
High extinction ratio CMZI AM—Experimental

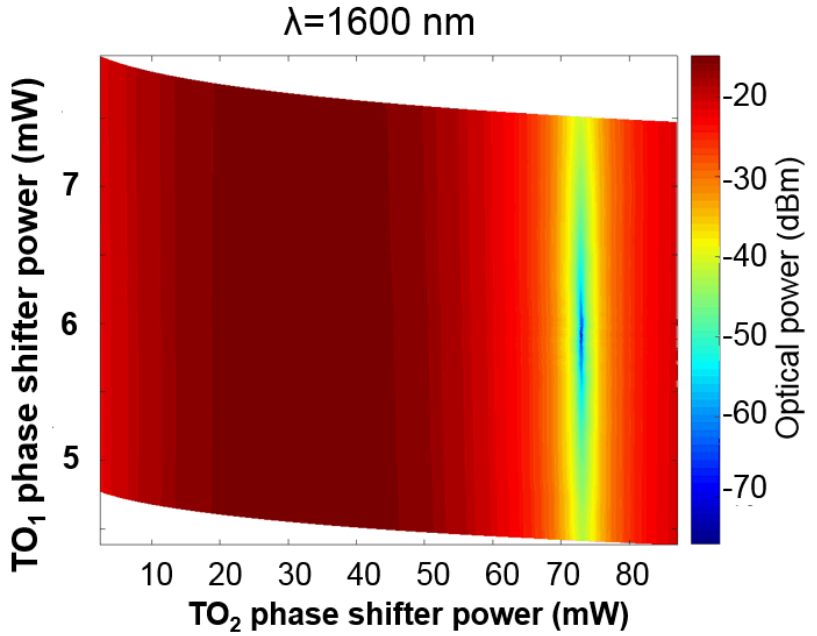


$$\frac{P_{5b}}{P_{5c}} = \frac{R_{3c}}{R_{3b}}$$

$$\frac{P_{5b}}{P_{5c}} = \frac{R_{3b}}{R_{3c}}$$







Broadband ultrahigh extinction ratio operation

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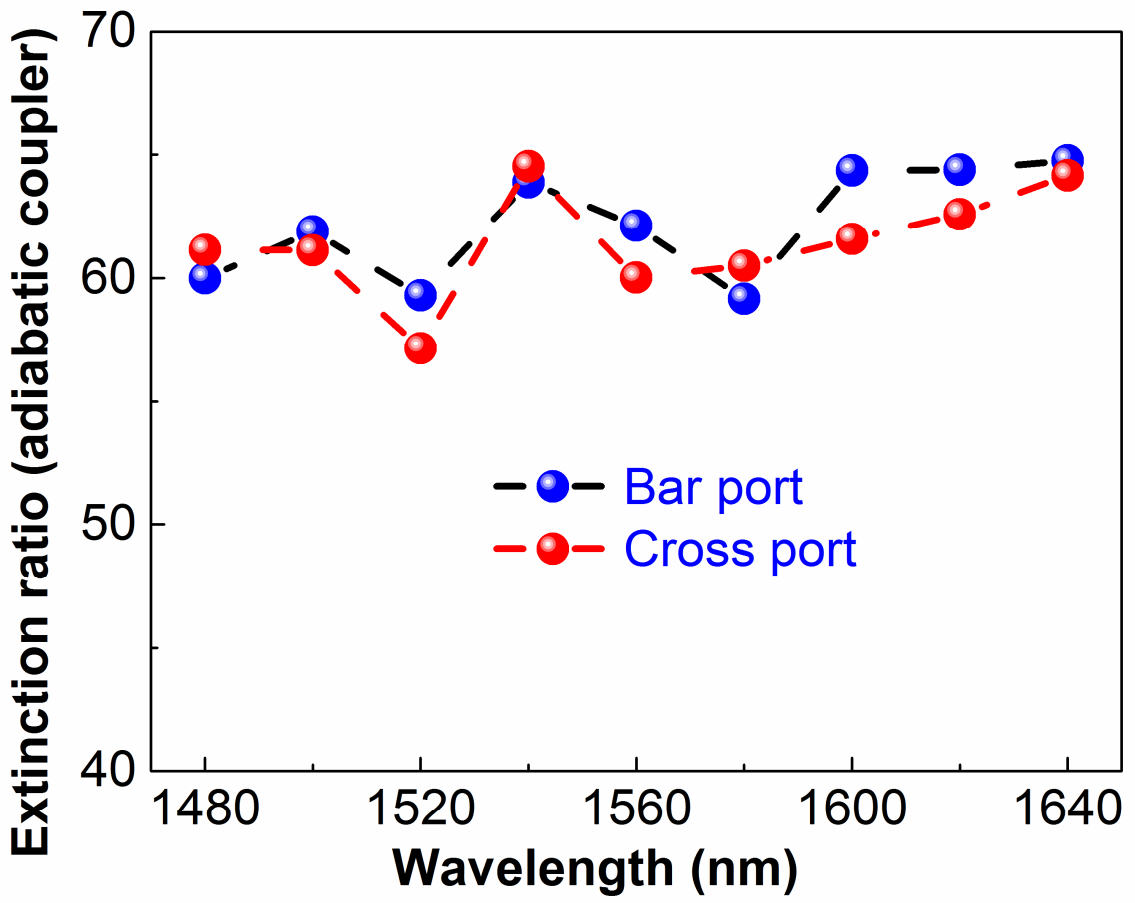
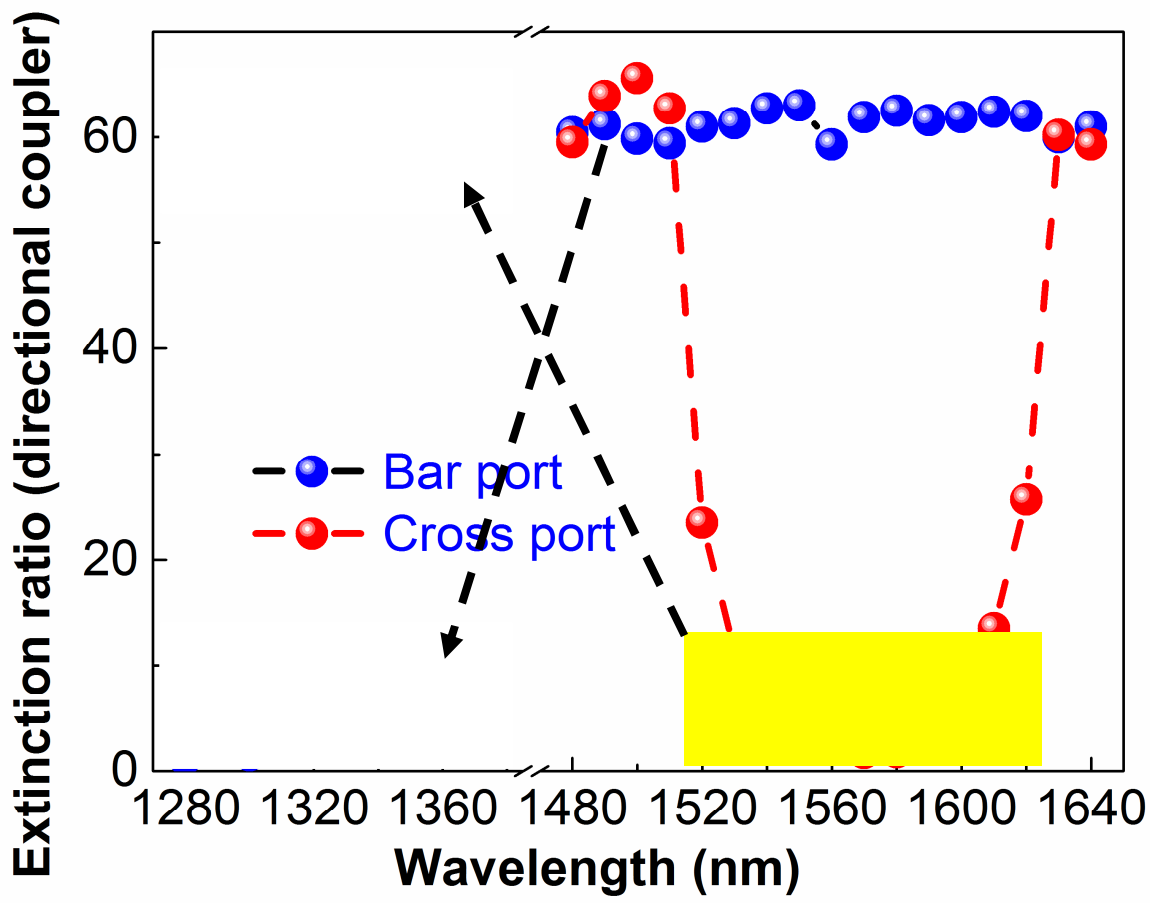
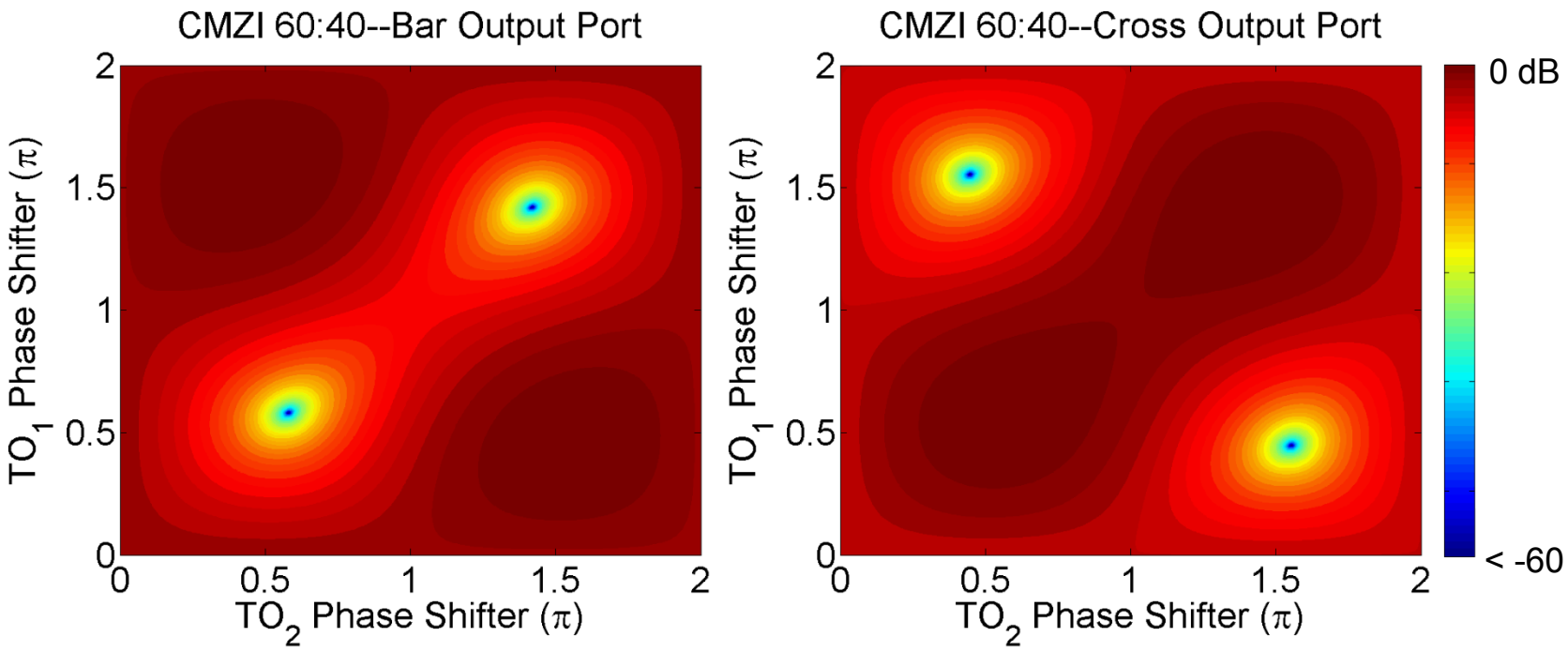
Adiabatic coupler—insensitive: 60/40—40/60

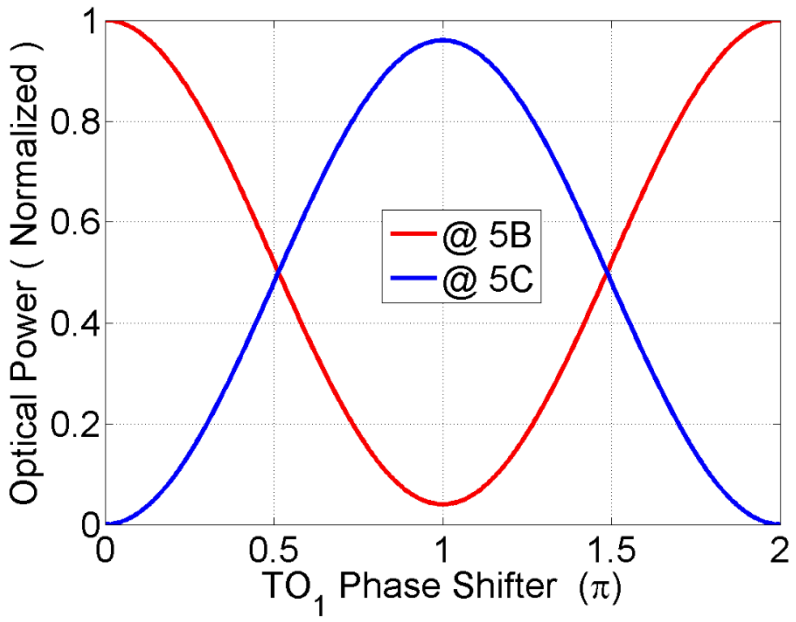


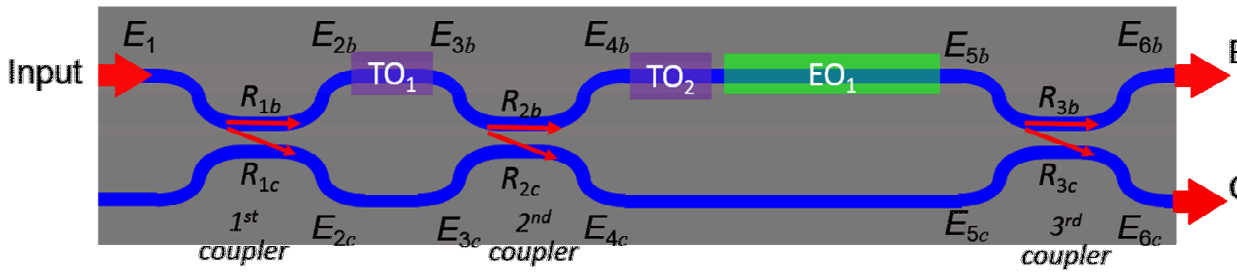
Hybrid coupler—sensitive: 100/0—0/100



Understanding CMZI AM (calculation)



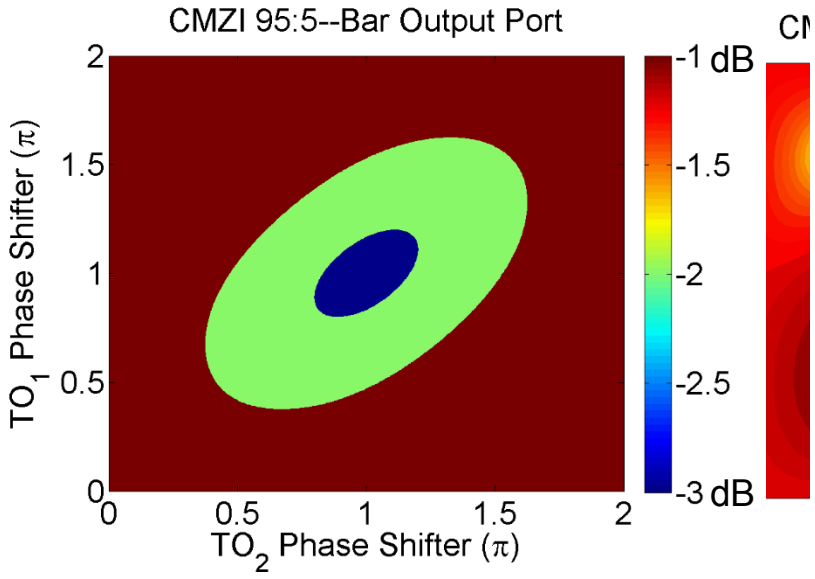


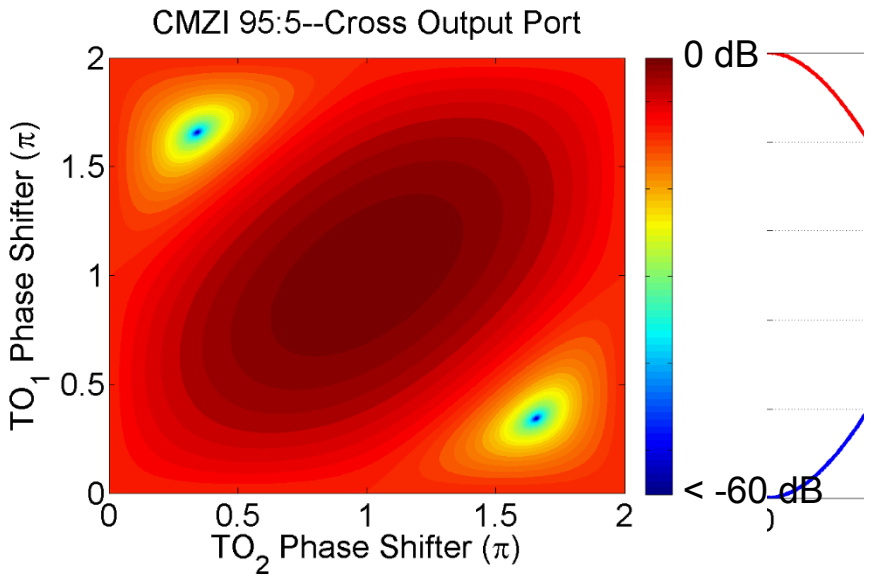


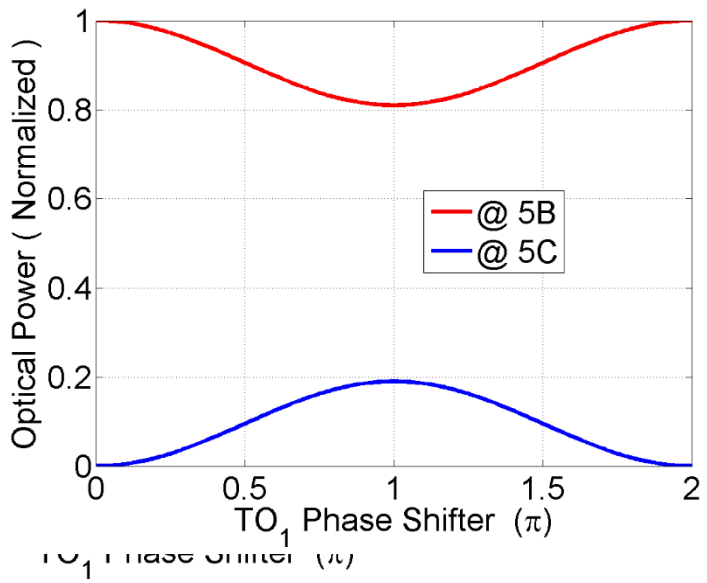
$$\frac{P_{5b}}{P_{5c}} = \frac{R_{3c}}{R_{3b}}$$

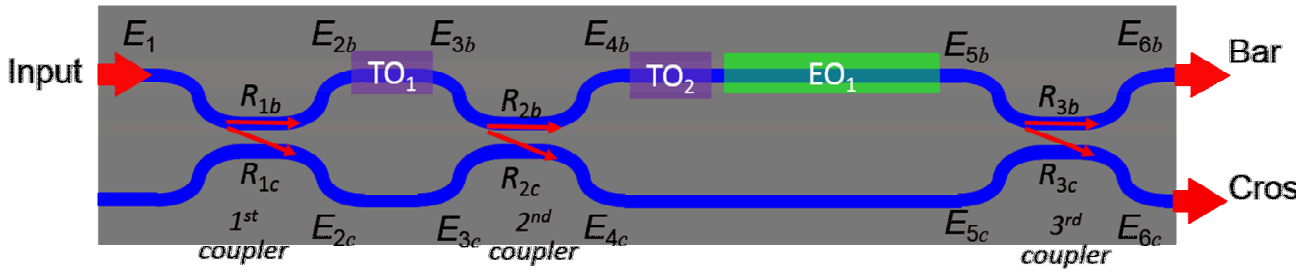
$$\frac{P_{5b}}{P_{5c}} = \frac{R_{3b}}{R_{3c}}$$

Understanding CMZI AM—cont. (calculation)









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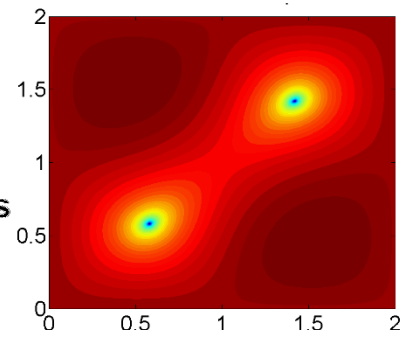

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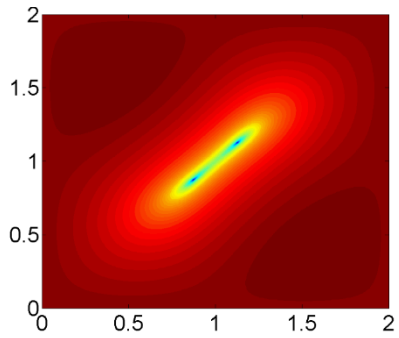

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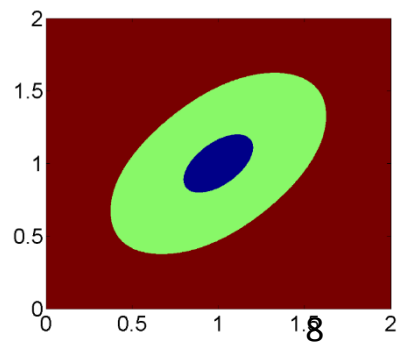

High speed measurement—CMZI AM

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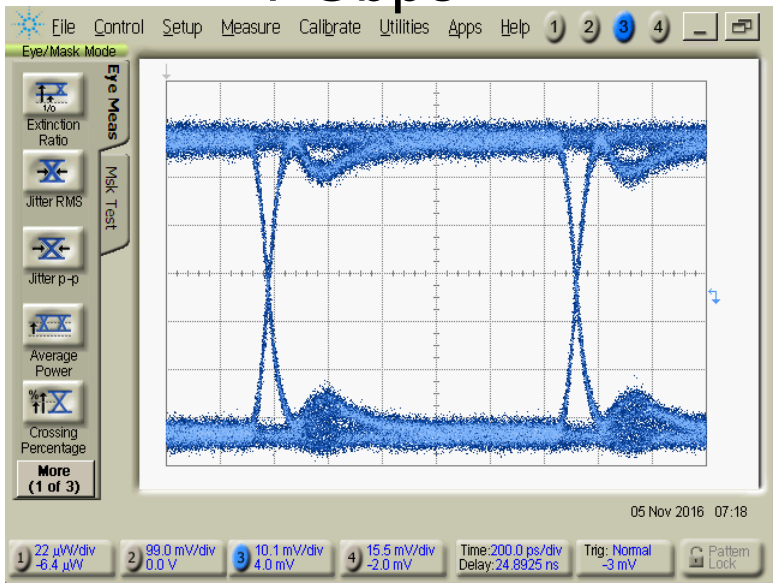
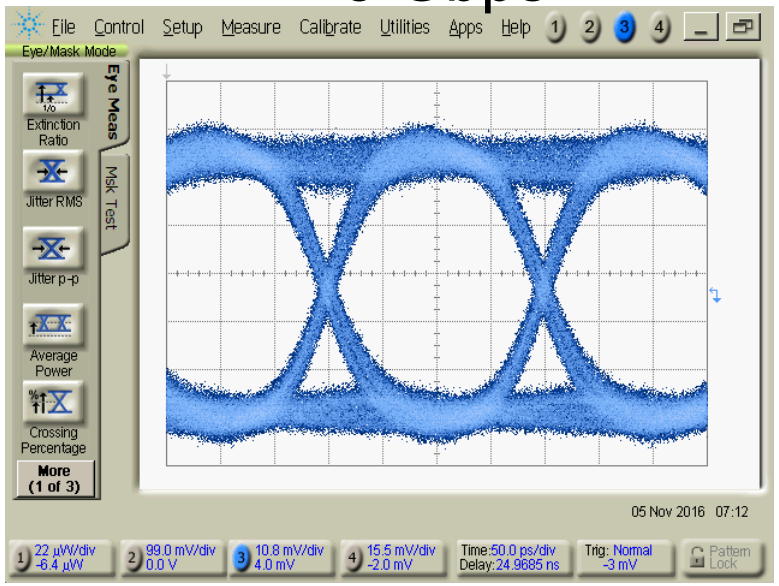
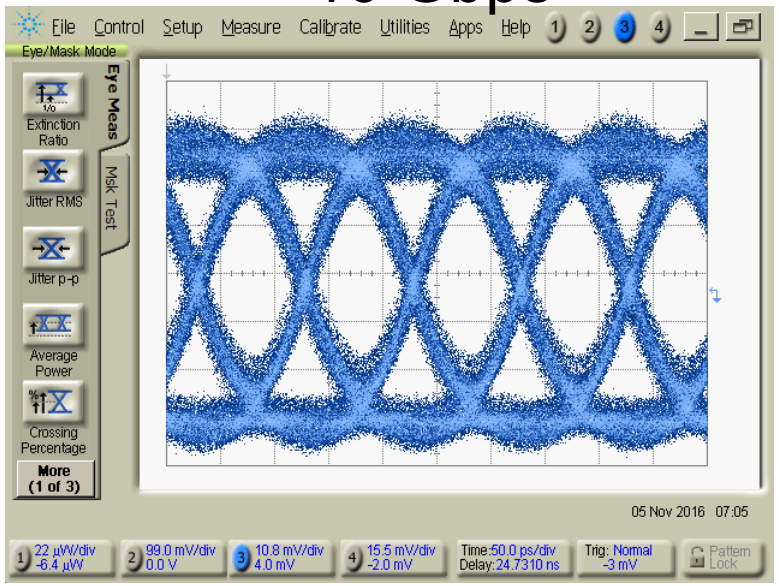
1 Gbps

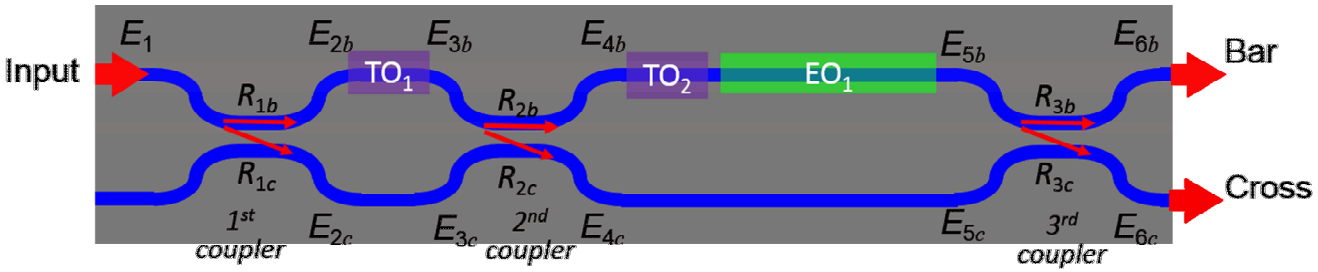


5 Gbps

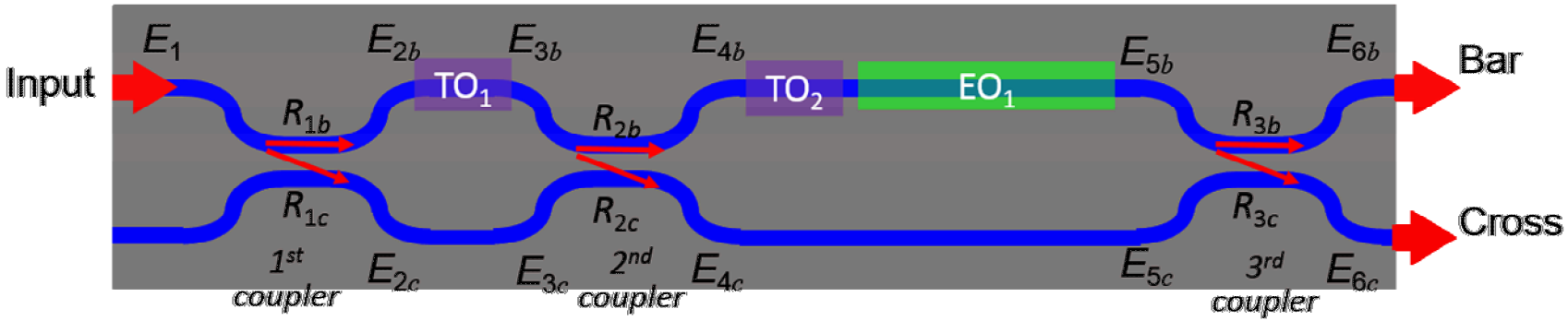


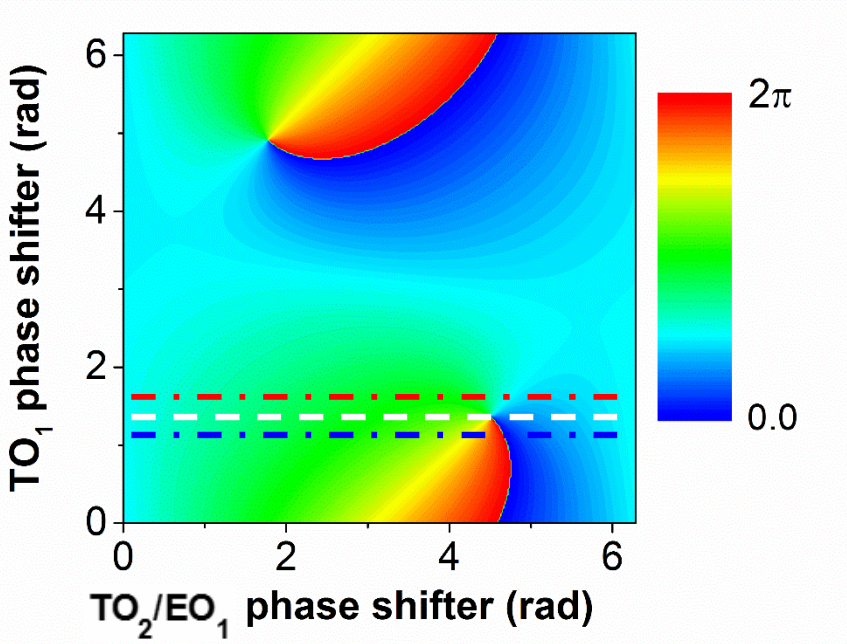
10 Gbps

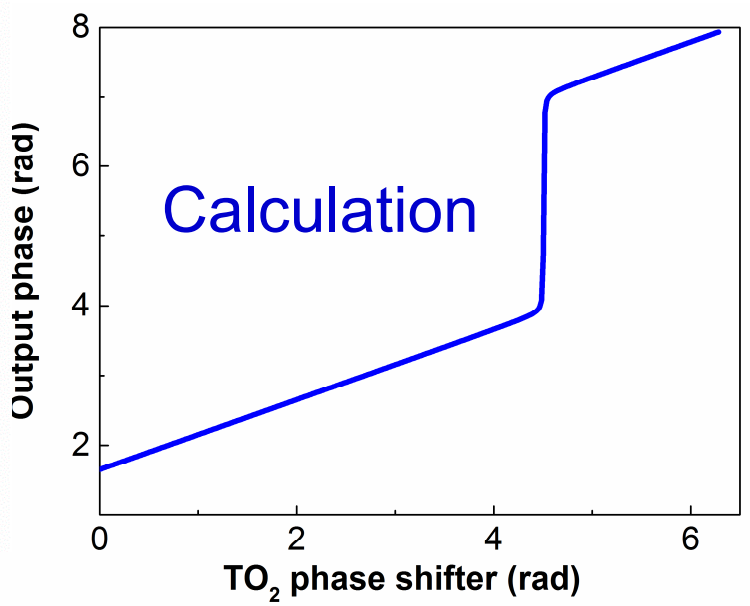


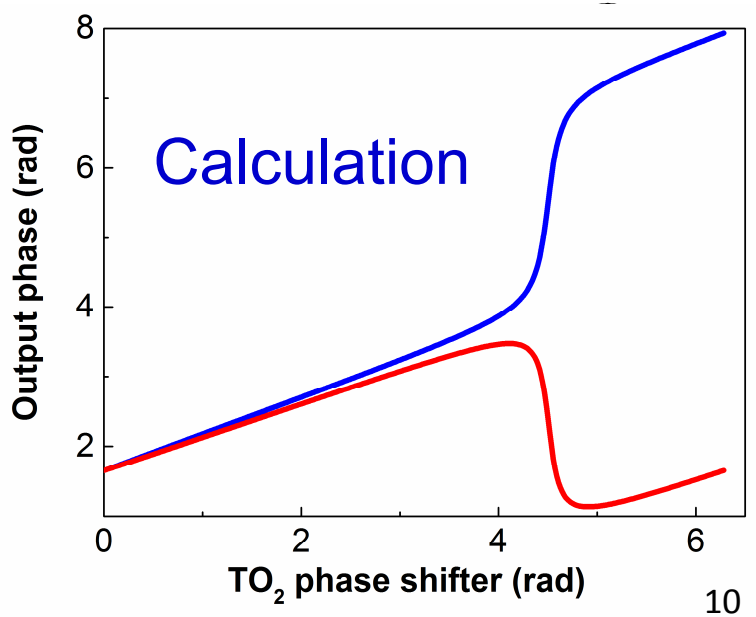


Output Phase of CMZI AM (calculation vs measurement)

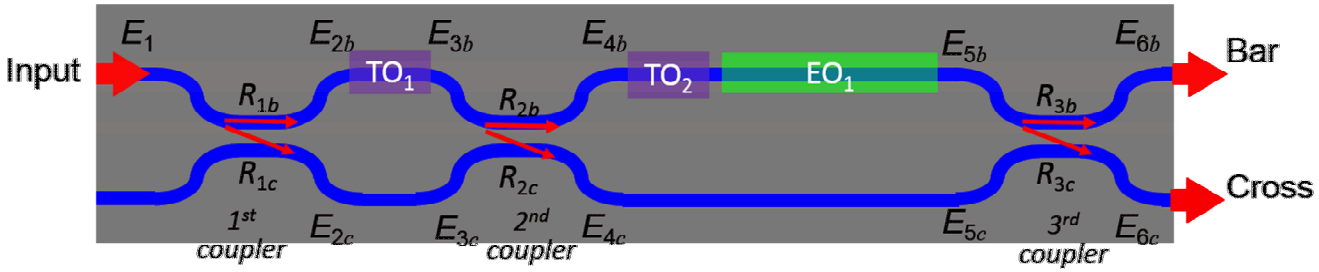


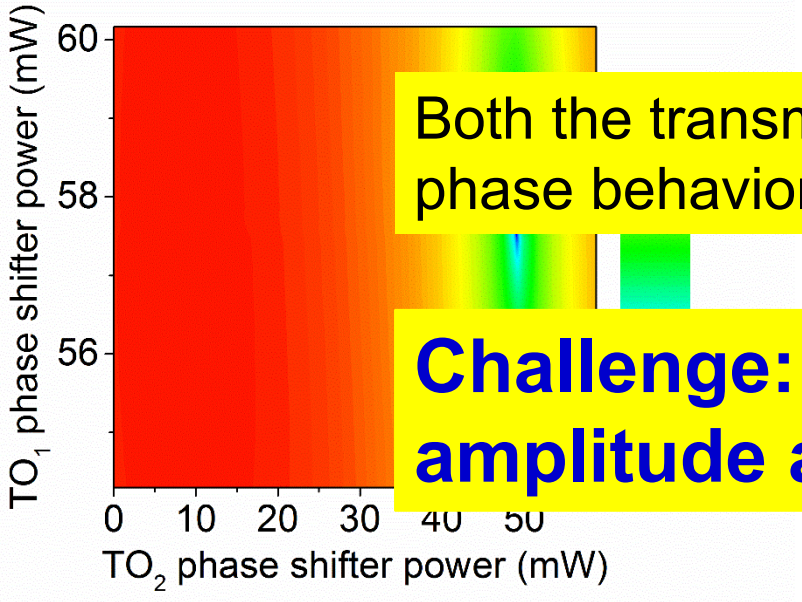


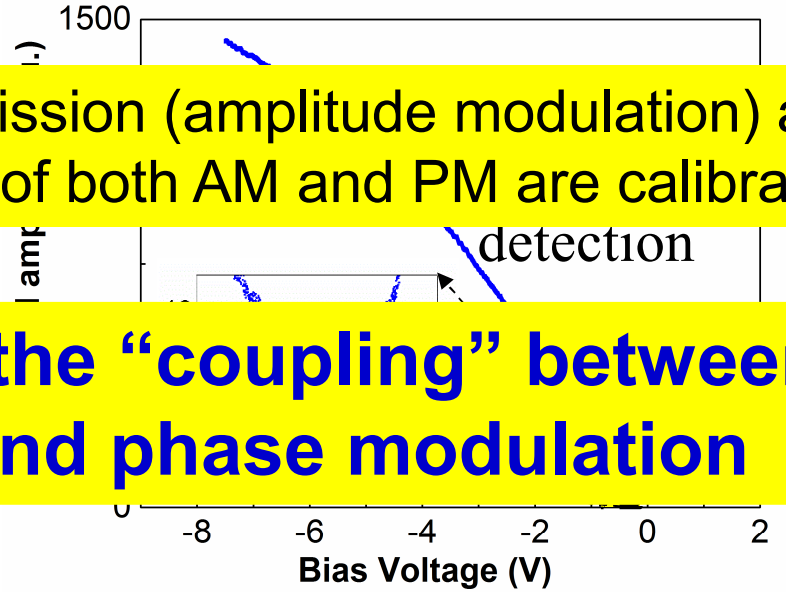


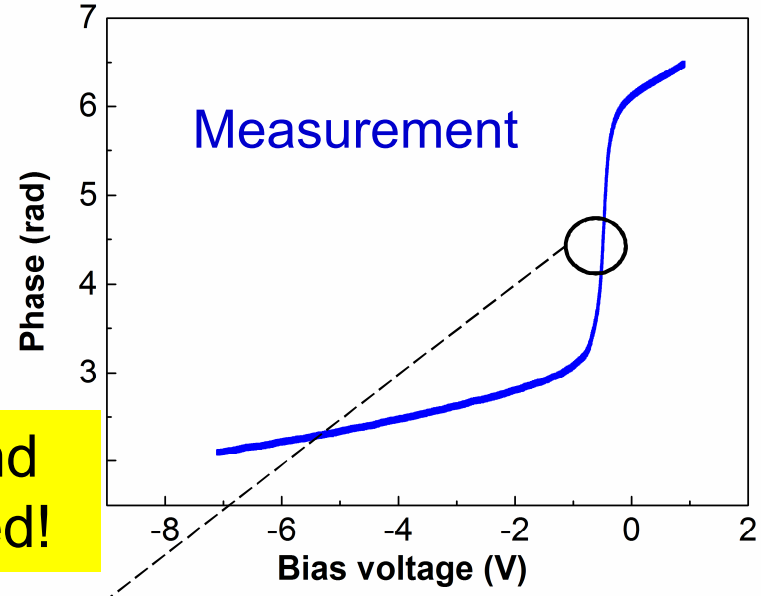


AM calibration



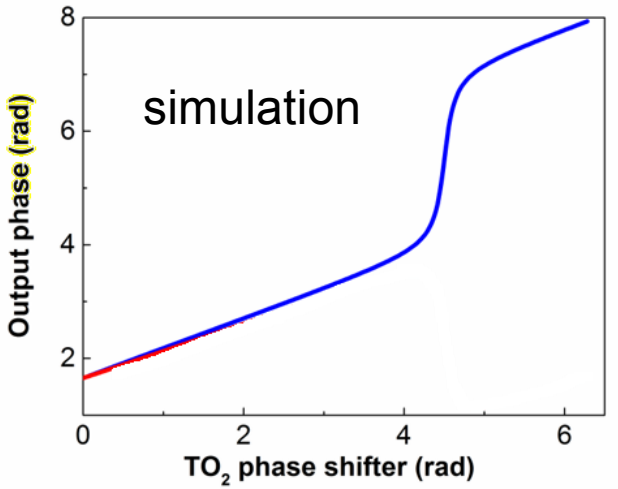






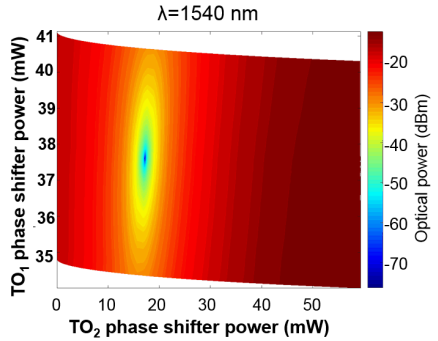
Both the transmission (amplitude modulation) and phase behavior of both AM and PM are calibrated!

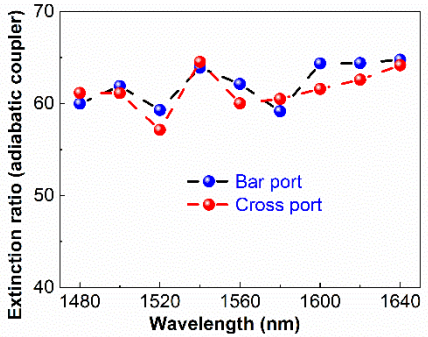
Challenge: the "coupling" between amplitude and phase modulation

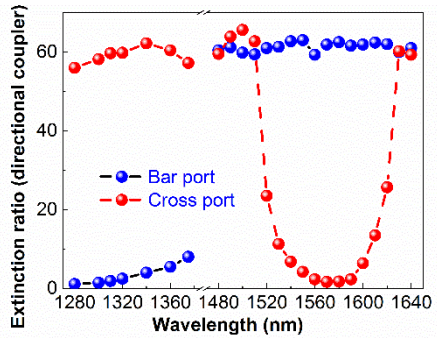


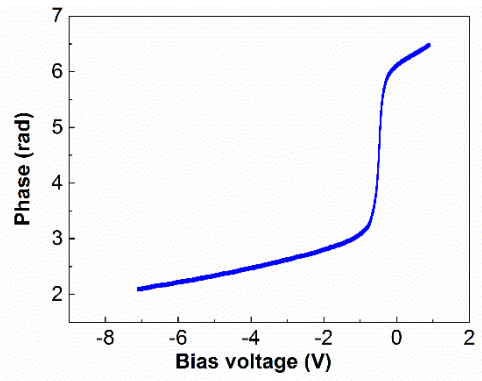
Thank you

- Demonstrate ultrahigh (>65 dB) extinction ratio AM
- Ultra-broadband operation
- High speed operation
- Output phase characterization









T-QUAKE (Transceiver for Quantum Keys and Encryption). see https://youtu.be/hk2XU_k1ZDI