SAND2017-5332C

Demonstration of a Silicon Photonic Transceiver for Polarization-Based Discrete Variable Quantum Key Distribution

Hong Cai, Christopher M. Long, Christopher T. DeRose, Nicholas Boynton, Junji Urayama, Andrew Pomerene, Andrew L. Starbuck, Douglas C. Trotter, Paul S. Davids, and Anthony L. Lentine

Sandia National Laboratories, Albuquerque, NM 87185, USA

hcai@sandia.gov

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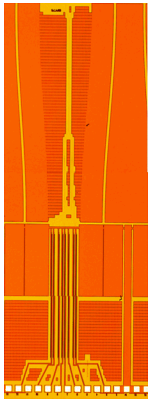
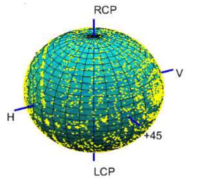
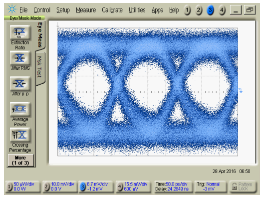
Outline

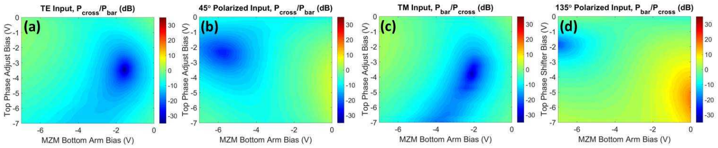


- Motivation
- Silicon Photonic (SiP) Transceiver Design and Operation
- Polarization Encoding

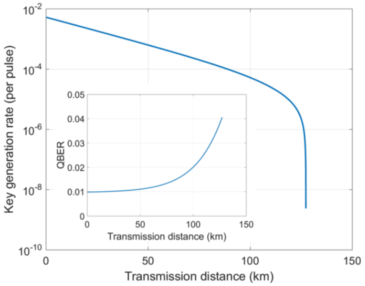




- Polarization Decoding



- Discussion
- Summary



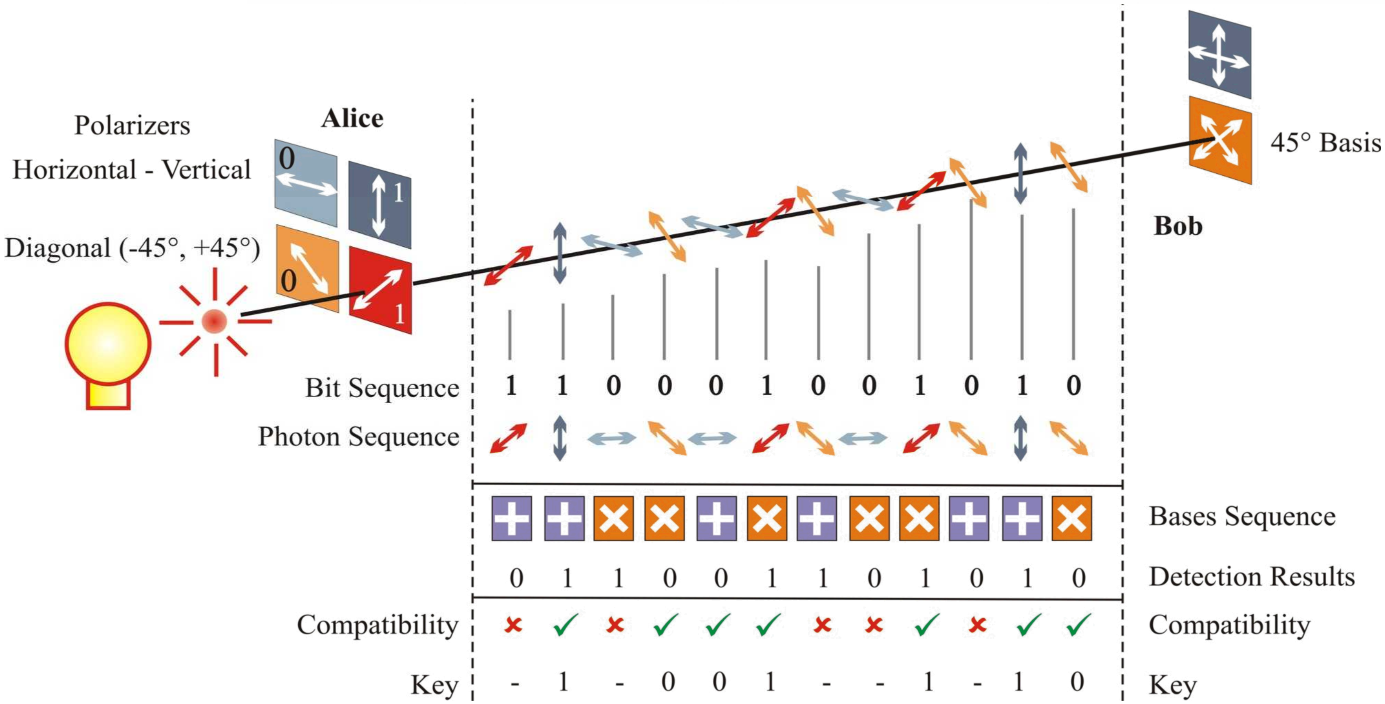
Motivation

- Quantum Key Distribution (QKD)
- BB84

QUANTUM CRYPTOGRAPHY: PUBLIC KEY DISTRIBUTION AND COIN TOSSING

Charles H. Bennett (IBM Research, Yorktown Heights NY 10598 USA)
Gilles Brassard (dept. IRO, Univ. de Montreal, H3C 3J7 Canada)

International Conference on Computers, Systems & Signal Processing Bangalore, India December 10-12, 1984



A Discrete Variable QKD (DV-QKD) Protocol, A Polarization-Based QKD Protocol….

Figure from http://swissquantum.idquantique.com/?Key-Sifting

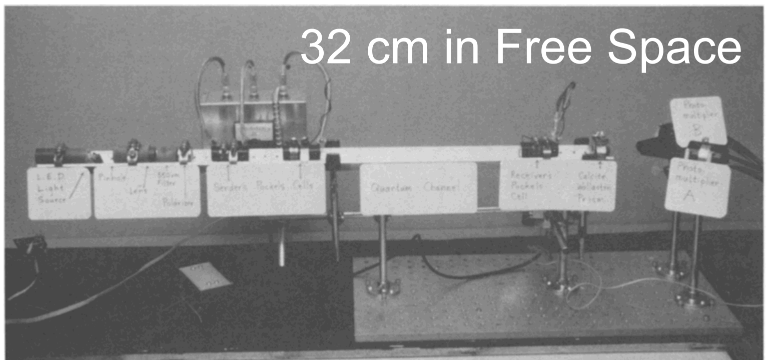
Motivation

Journal of Cryptology
January 1992, Volume 5, Issue 1, pp 3–28

Experimental quantum cryptography

Authors   Authors and affiliations

Charles H. Bennett, François Bessette, Gilles Brassard, Louis Salvail, John Smolin



32 cm in Free Space

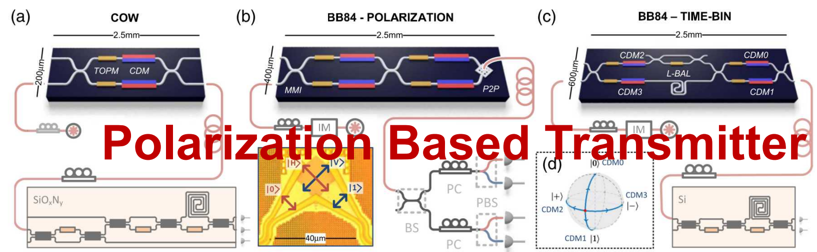
Silicon Photonic (SiP) Transceiver

> 200 km in Fiber

Decoy-state quantum key distribution with polarized photons over 200 km

Yang Liu, Teng-Yun Chen, Jian Wang, Wen-Qi Cai, Xu Wan, Luo-Kan Chen, Jin-Hong Wang, Shu-Bin Liu, Hao Liang, Lin Yang, Cheng-Zhi Peng, Kai Chen, Zeng-Bing Chen, and Jian-Wei Pan

Optics Express **18**, 8587 (2010)



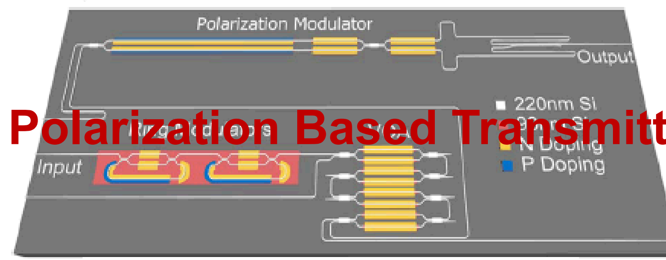
Polarization Based Transmitter

Research Article   Vol. 4, No. 2 / February 2017 / Optica   172

optica

Integrated silicon photonics for high-speed quantum key distribution

Philip Sibson,[1,3] Jake E. Kennard,[1] Stasja Stanisic,[1,2] Chris Erven,[1] Jeremy L. O'Brien,[1] and Mark G. Thompson[1,*]



Polarization Based Transmitter

Research Article   Vol. 3, No. 11 / November 2016 / Optica   1274

optica

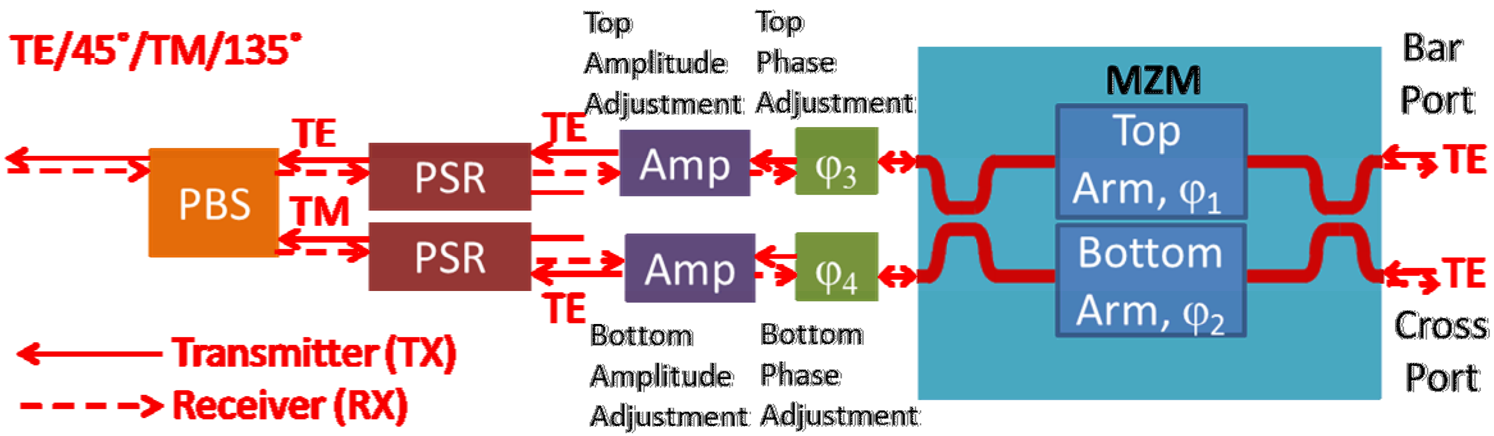
Silicon photonic transmitter for polarization-encoded quantum key distribution

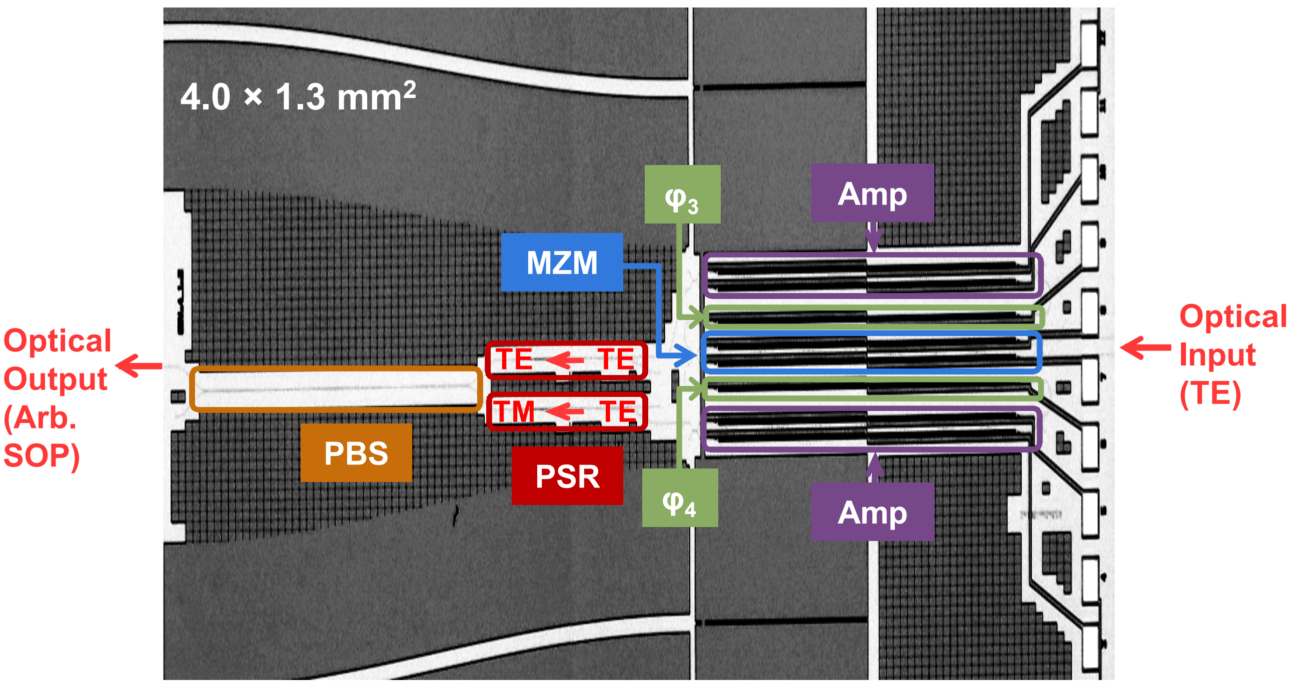
Chaoxuan Ma,[1,7,*] Wesley D. Sacher,[1,2,7] Zhiyuan Tang,[3,7] Jared C. Mikkelsen,[1] Yisu Yang,[1] Feihu Xu,[1,4] Torrey Thiessen,[1] Hoi-Kwong Lo,[1,3] and Joyce K. S. Poon[1,5]

A Full SiP Transceiver for Polarization-Based DV-QKD?

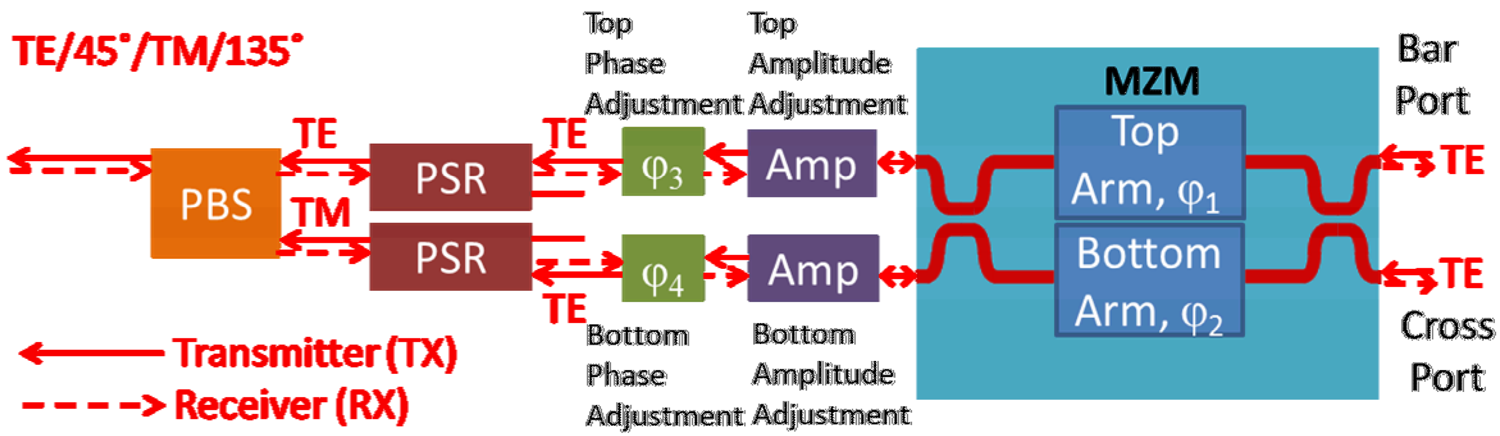
Here it is!

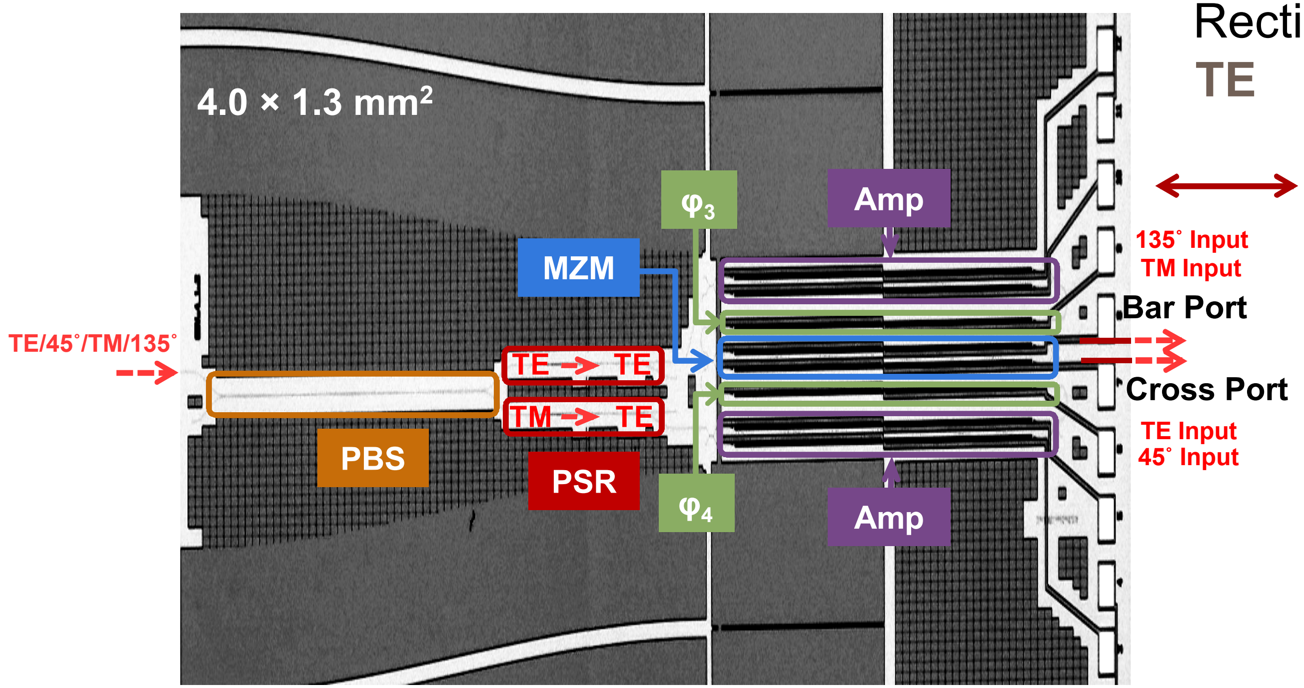
SiP Transceiver Design and Operation

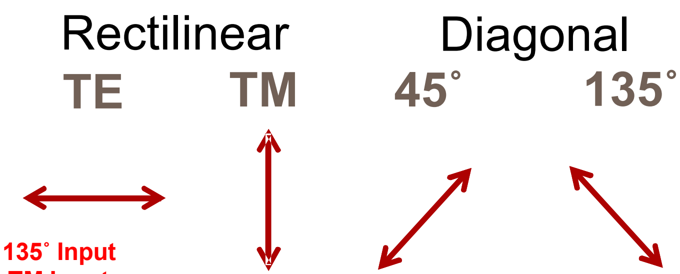




SiP Transceiver Design and Operation







- A full transceiver for polarization encoding and decoding
- A common structure for both transmitting and receiving

Polarization Encoding

Stokes Vector

$$S = (s_0\ s_1\ s_2\ s_2)^T$$

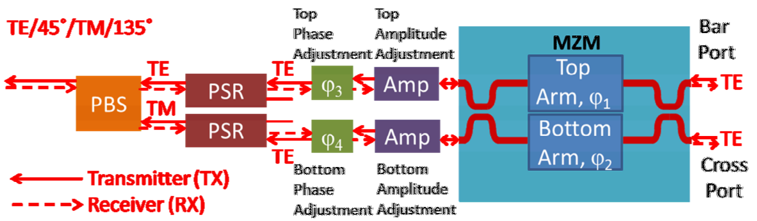
$$s_0 = I$$

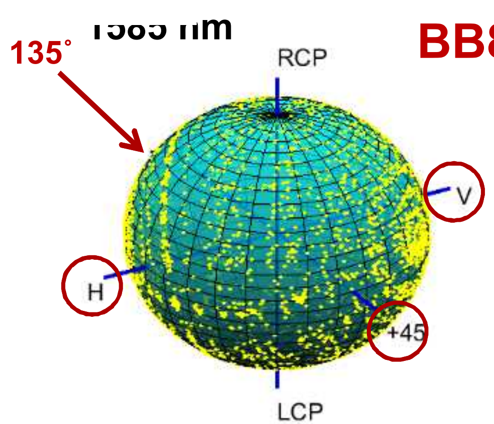
$$s_1 = H - V$$

$$s_2 = 45^{\circ} - 135^{\circ}$$

$$s_3 = RCP - LCP$$

BB84 States	S			
	s_0	s_1	s_2	s_3
TE	1	1	0	0
45°	1	0	1	0
TM	1	-1	0	0
135°	1	0	-1	0

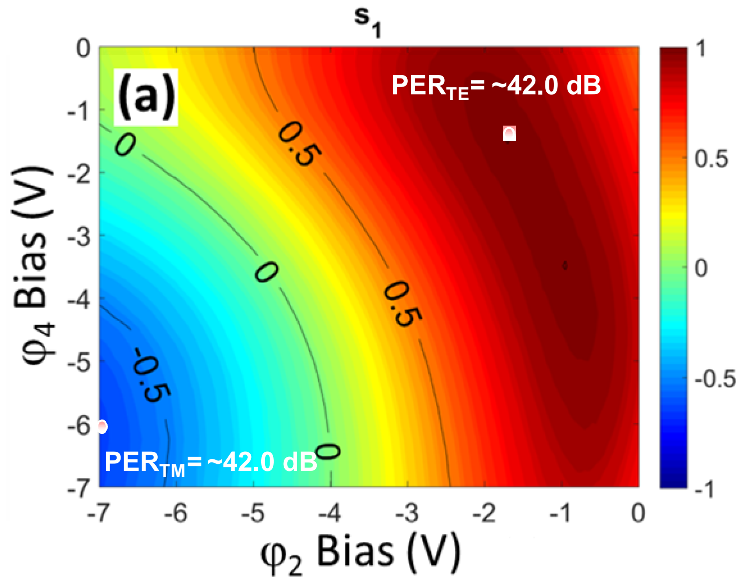


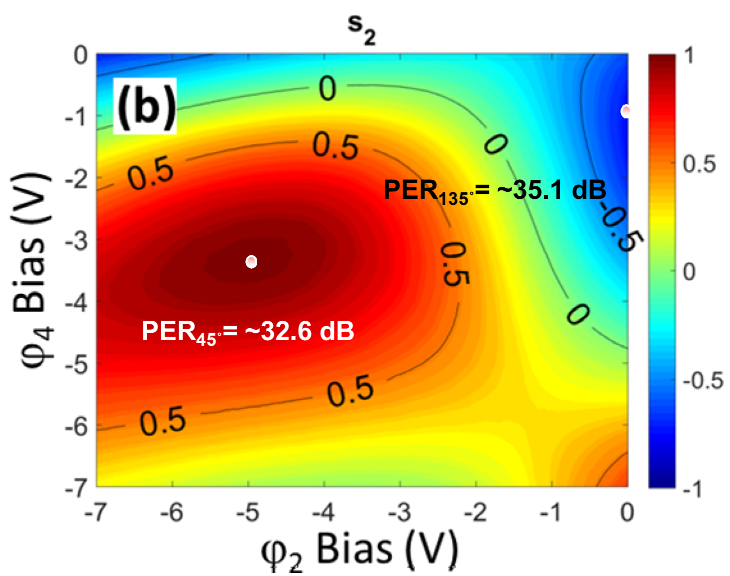


BB84 States!

How “pure”?

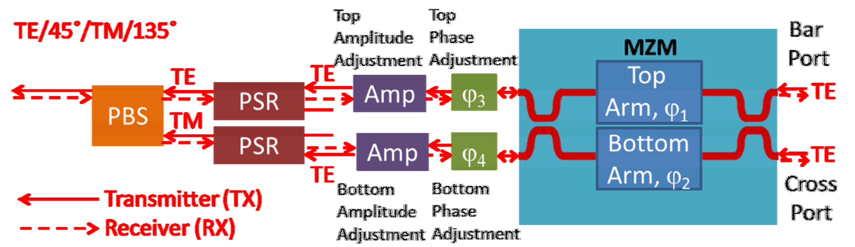
Polarization Encoding, PER





DOP > 0.9885

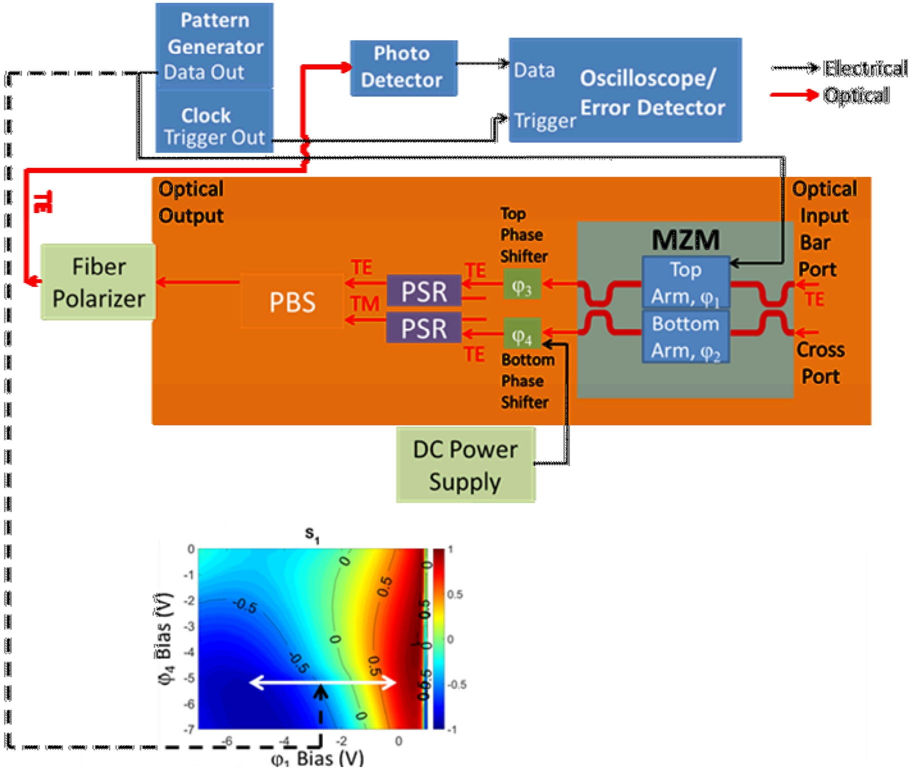
- Flexibilities in operation….
  - ✓ Combination of phase shifters,
  - ✓ and Bias Polarity for Each BB84 State

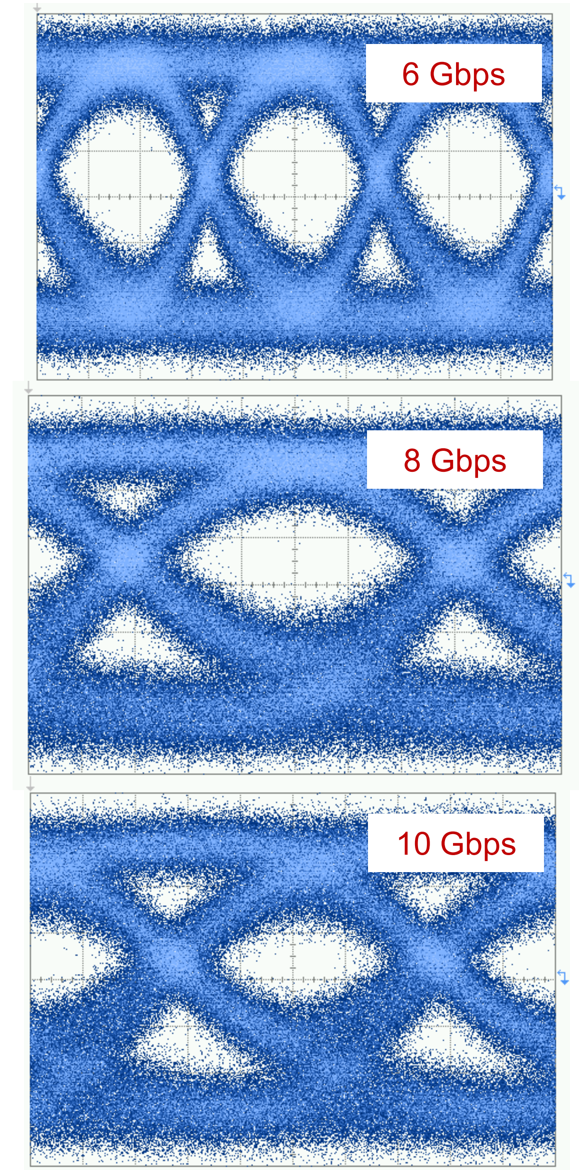


- From Other Tests on the Same Device

State of Polarization (SOP)	PER (dB)
TE	~31.2
45°	~34.2
TM	~37.3
135°	~37.6

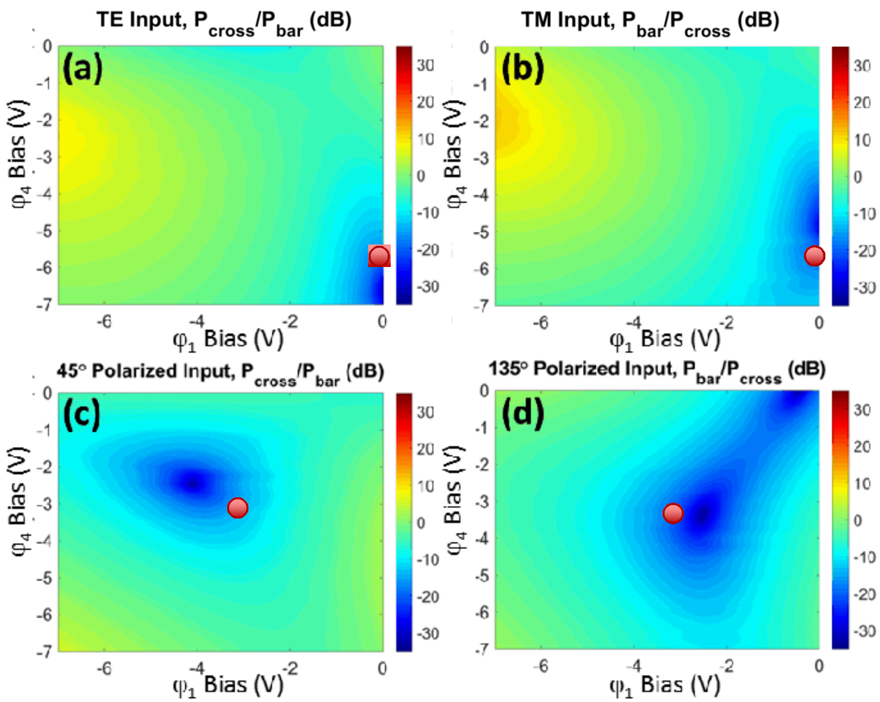
High Speed Polarization Modulation





Data Rate (Gbps)	Conventional Bit Error Rate (s^{-1})
≤ 6	Error Free for > 5 min
8	2.5×10^{-11}
10	9.0×10^{-11}

Polarization Decoding



$$ER_{TE} = 10 \cdot log_{10}\left(\frac{P_{cross}}{P_{bar}}\right)$$

Operational ER, Lower ER of the Two Polarizations in a basis with the Same Phase Shifter Settings

RX Decoding for Reverse Bias Condition

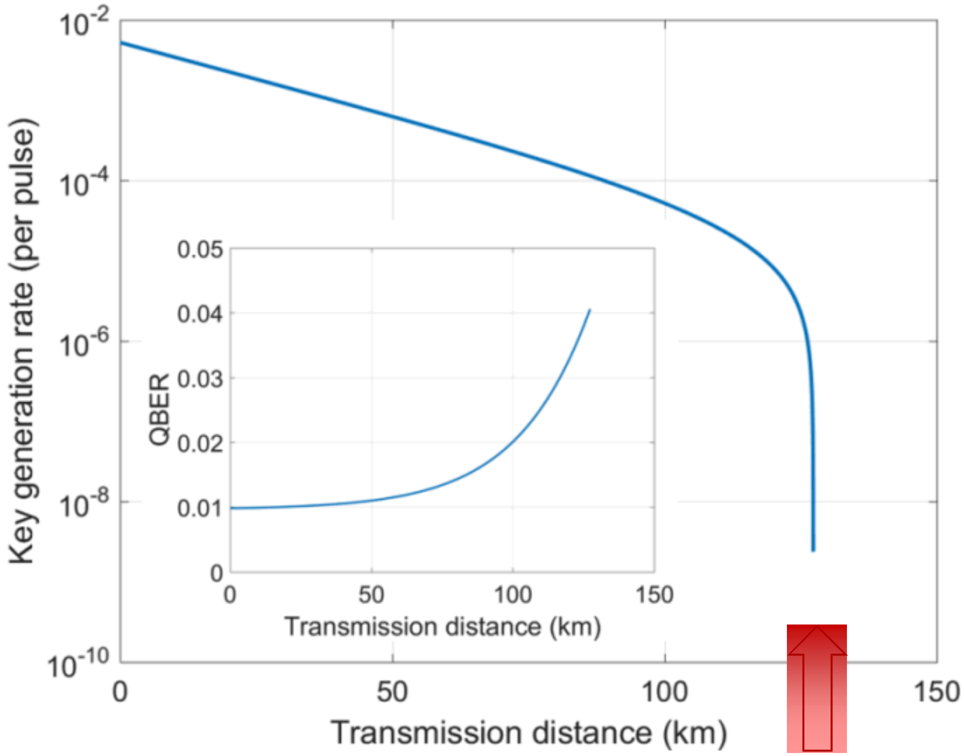
Polarization	Optimal operational ER of polarization basis (dB)	Insertion loss at optimal operational ER setting (dB)
TE	18.4	3.7
TM		6.7
45˚	16.5	4.6
135˚		5.4

RX Decoding for Mixed Bias Condition

Polarization	Optimal operational ER of polarization basis (dB)	Insertion loss at optimal operational ER setting (dB)
TE	20.7	5.5
TM		7.5
45˚	20.5	6.3
135˚		6.5

Discussion, Simulation of Key Generation Rate

Parameter	Value	Unit
Expected photon number of the signal [1]	0.81	
Detection Efficiency [2]	70	%
Dark count probability [2]	1.2×10^{-5}	
Fiber loss[3]	0.18	dB/km
TX PER	31.2	dB
RX ER	20.5	dB
RX insertion loss	7.6	dB (coupling loss not included)
Fiber to Waveguide coupling loss	1.5	dB/interface

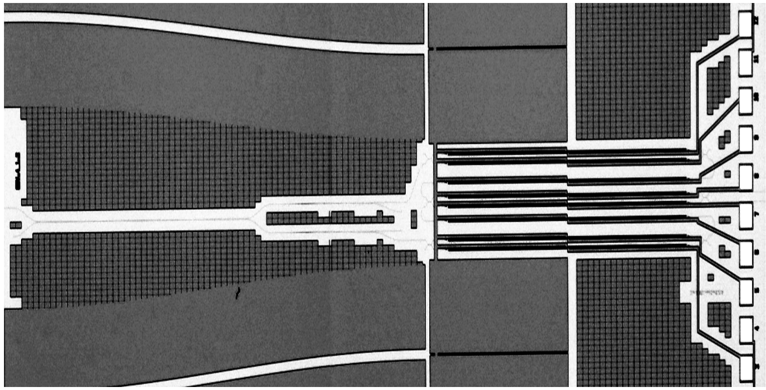


[1] X. Ma, B. Qi, Y. Zhao, and H.-K. Lo, "Practical decoy state for quantum key distribution," Phys. Rev. A 72, 012326 (2005).
[2] Multi-channel SNSPD closed-cycle system (Single Quantum, http://www.singlequantum.com/wp-content/uploads/2016/10/Single-Quantum-Eos.pdf).
[3] Corning SMF-28 Ultra Optical Fiber (Corning Inc., https://www.corning.com/media/worldwide/coc/documents/Fiber/SMF-28%20Ultra.pdf).

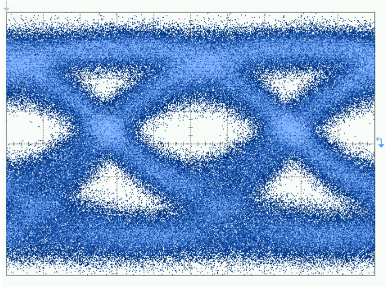
Maximal Transmission Distance, 127 km Implementing BB84

Summary

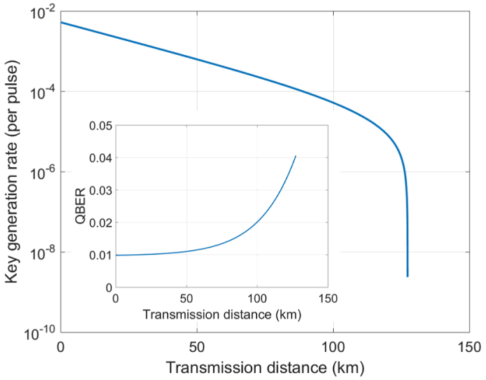
- A Full SiP Transceiver for Polarization- Based DV-QKD
  - ✓ A Common Structure for Polarization Encoding and Decoding
  - ✓ Encoding PER > 30 dB
  - ✓ Decoding ER >20 dB
  - ✓ Loss Insertion Loss
  - ✓ High Speed Operation



10 Gbps



- ~127 km Expected Maximal Transmission Distance



Thank you!

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Discussion, in the Fiber Channel

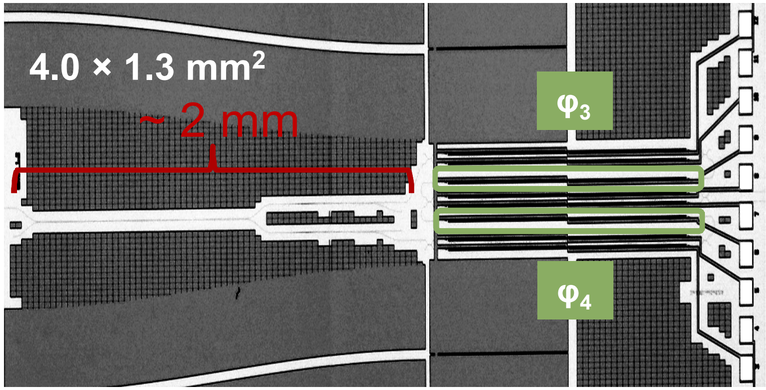
Question 1, Polarization Rotation

Polarization Basis	Optimal operational ER (dB)
Rectilinear	14.2
15˚/105˚	13.1
30˚/120˚	20.8
Diagonal	15.5
60˚/150˚	14.3
75˚/165˚	14.1

Question 2, Polarization Mode Dispersion (PMD)

~127 km Fiber

0.5 ps Temporal Delay



~2 mm Waveguide, $n_{g,TE}$= 4.45, $n_{g,TM}$= 3.68

5.0 ps Temporal Delay

Answer, Compensate using φ_3 and φ_4!