Proposal for 800G-LR4 Optical PMD Based on DP-PAM4

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Supporters

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- Frank Chang (Source)
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Overview

- This proposal is to employ dual-polarization (DP) IM-DD transmission (coherent already employs DP transmission) to enable 800G-LR4 links using current 100G PAM4 PHY, while avoiding dispersion and FWM penalties.
- Outline
  - Overview of DP transmit and reception
  - Comparison with other 800G LR options
  - WDM DP configurations
  - Performing polarization demultiplexing with integrated optics
  - Recent publications on polarization demultiplexers
  - Simulation results
  - Link budget
  - Polarization demultiplexer tracking speed requirements
  - Conclusion

Baseline links

Baseline Status as of May 17th

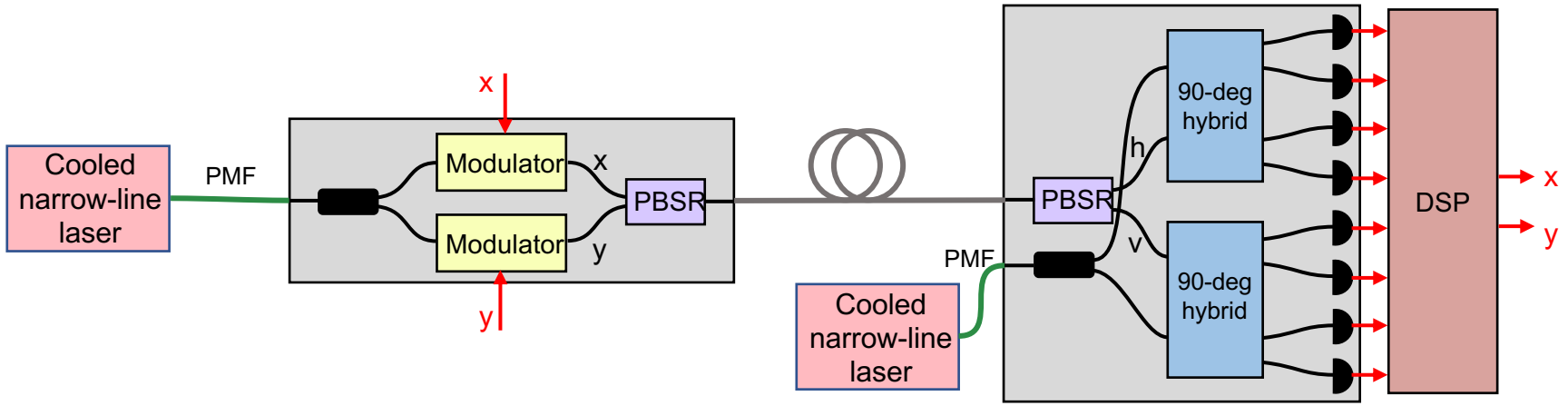
Ethernet Rate	Assumed Signaling Rate	AUI	BP	Cu Cable	MMF 50m	MMF 100m	SMF 500m	SMF 2km	SMF 10km	SMF 40km
200 Gb/s	200 Gb/s	Over 1 lane 200GAUI-1		Over 1 pair 200GBASE-CR1			Over 1 Pair TBD	Over 1 Pair TBD		
400 Gb/s	100 Gb/s							Over 4 Pair TBD		
	200 Gb/s	Over 2 lanes 400GAUI-2		Over 2 pairs 400GBASE-CR2			Over 2 Pair TBD			
800 Gb/s	100 Gb/s	Over 8 lanes 800GAUI-8	Over 8 lanes 800GBASE-KR8	Over 8 pairs 800GBASE-CR8	Over 8 pairs 800GBASE-VR8	Over 8 pairs 800GBASE-SR8	Over 8 pairs TBD	Over 8 pairs TBD		
	200 Gb/s	Over 4 lanes 800GAUI-4		Over 4 pairs 800GBASE-CR4			Over 4 pairs TBD	1) Over 4 pairs TBD 2) Over 4 λ's TBD		
	TBD								Over single SMF in each direction TBD	Over single SMF in each direction TBD
1.6 Tb/s	100 Gb/s	Over 16 lanes 1.6TAUI-16								
	200 Gb/s	Over 8 lanes 1.6TAUI-8		Over 8 pairs 1.6TBASE-CR8			Over 8 pairs TBD	Over 8 pairs TBD		

Target for this proposal

Adopted baselines

Dual polarization

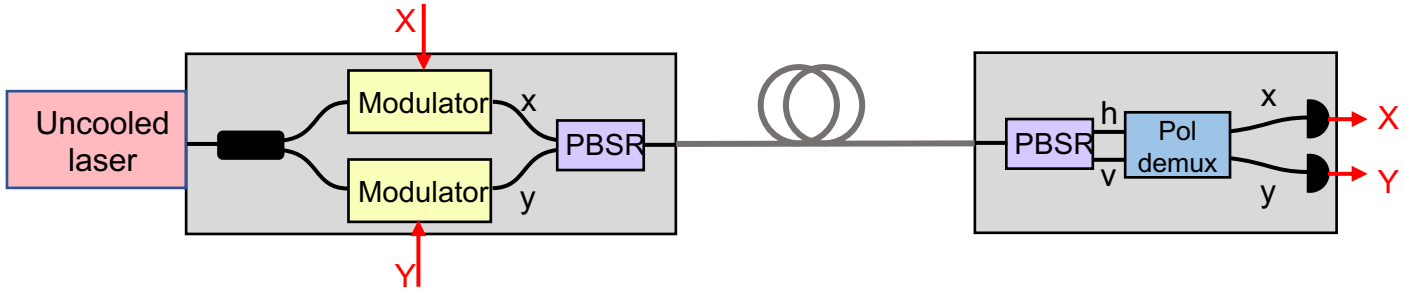
Coherent



MIMO demux done in digital electronics

Can do MIMO demux after coherent detection because interference with LO with ppm offset provides phase information

IM-DD



MIMO demux must be done in optics

Cannot do MIMO demux after square-law detection because of loss of phase information

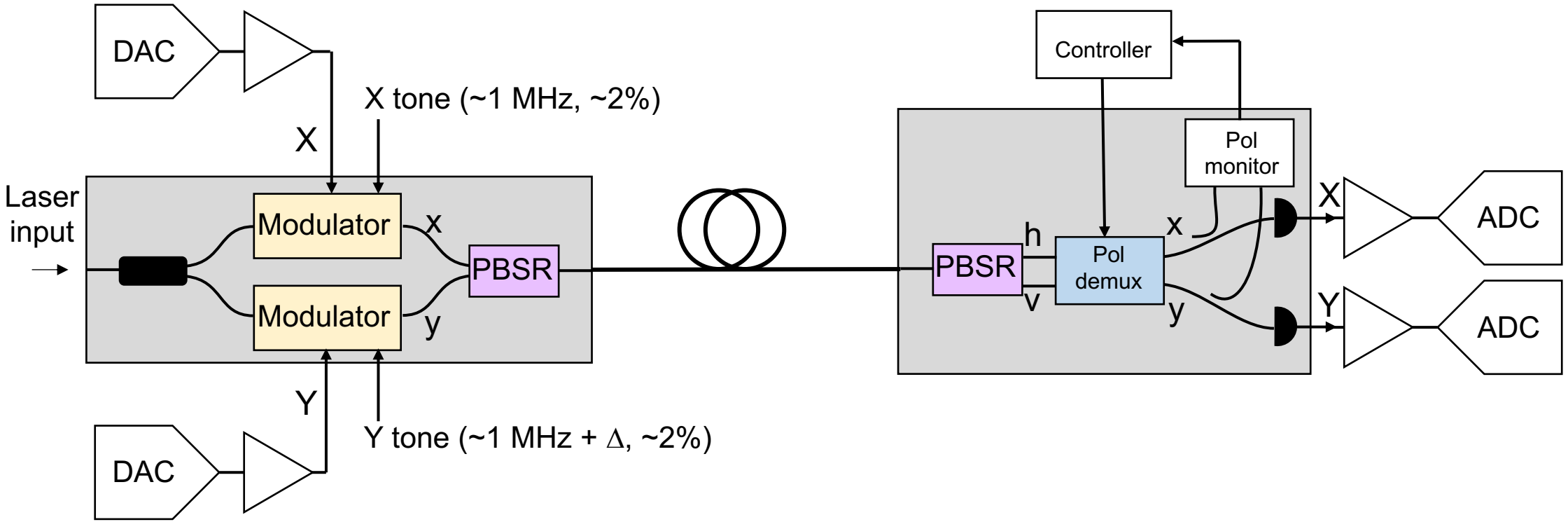
Some options for 800G LR (10 km)

λ qty	λ spacing	Baud rate	Format	Laser qty	Laser pwr	Cooled laser	Backward compatibility	KP4 FEC	Disp.	FWM	Time to market
8	20 nm	56 Gbaud	PAM4								
8	800 GHz	56 Gbaud	PAM4								
4	20 nm	112 Gbaud	PAM4								
4	10 nm	112 Gbaud	PAM4								
4	20 nm	56 Gbaud	DP-PAM4								

Our proposal

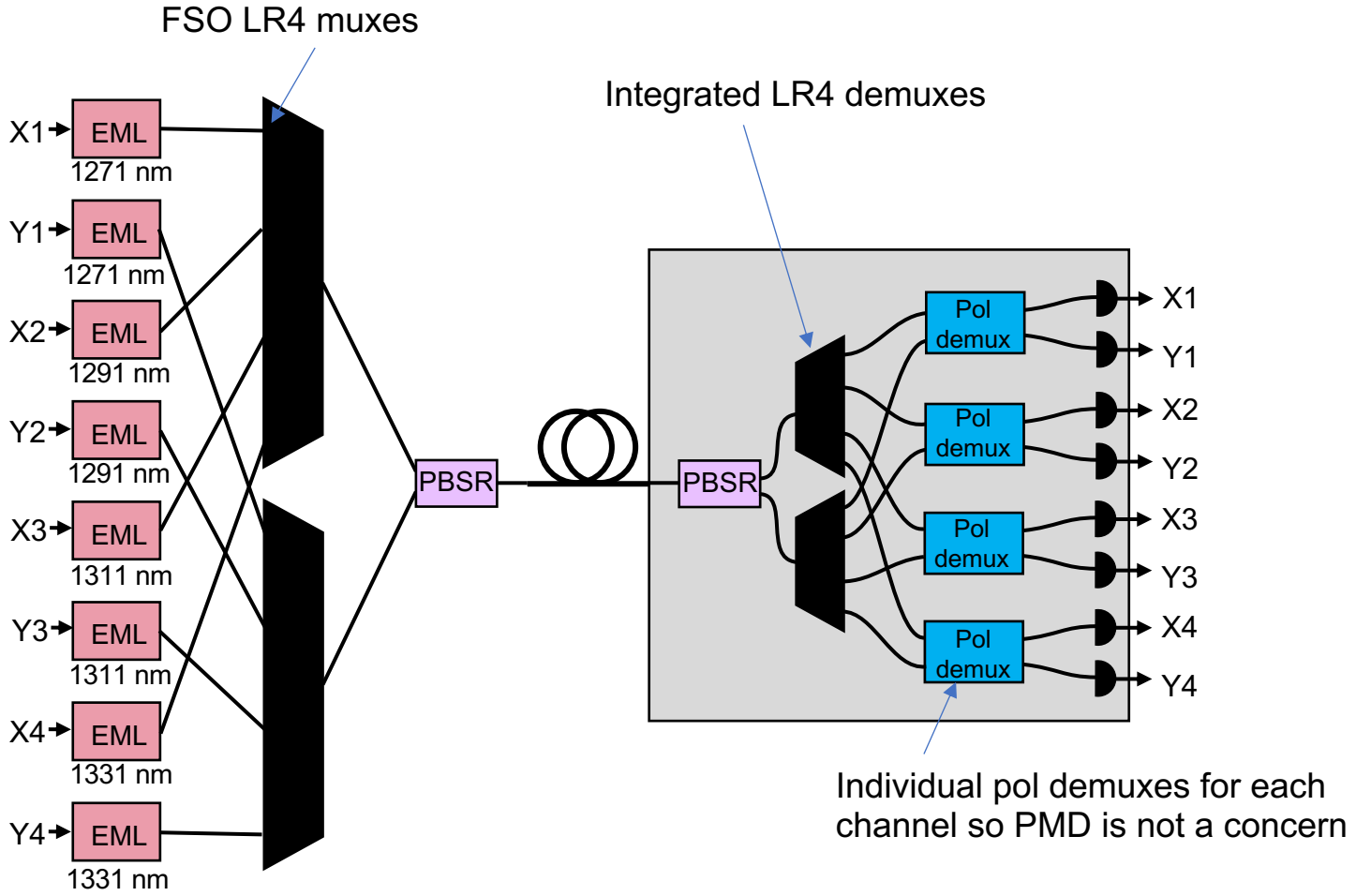
Marker tones

Two simple low-frequency marker tones are added at the transmitter to identify and aid in separating the X and Y polarizations in the receiver.

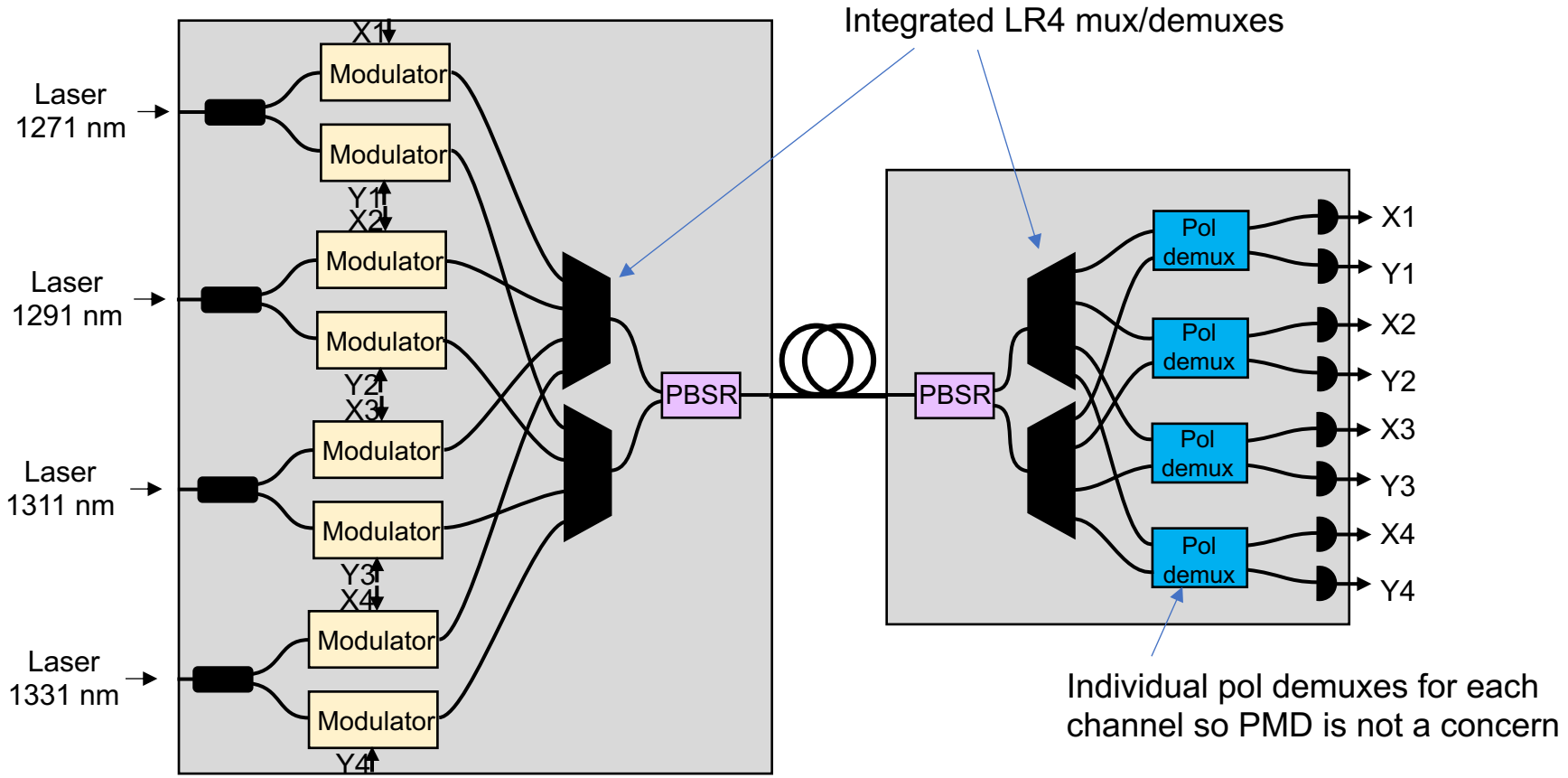


DP system is entirely agnostic to PHY and PCS

DP-PAM4 implementation of 800G LR4: EML Tx, SiPh Rx

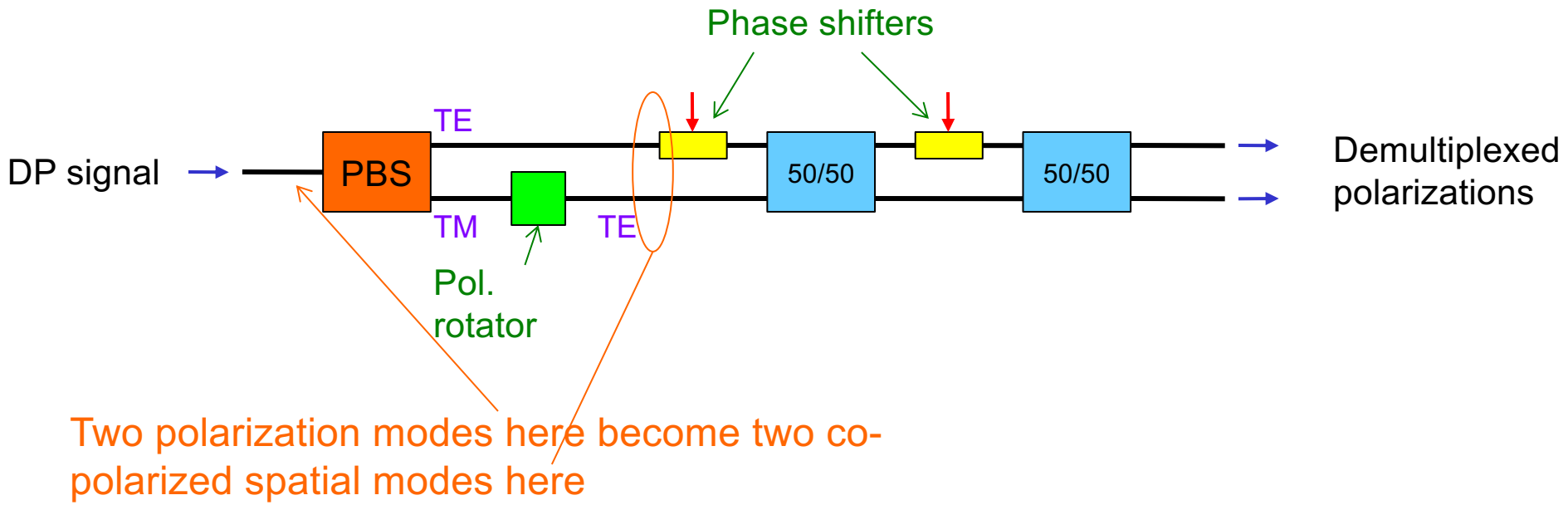


DP-PAM4 implementation of 800G LR4: SiPh Tx, SiPh Rx



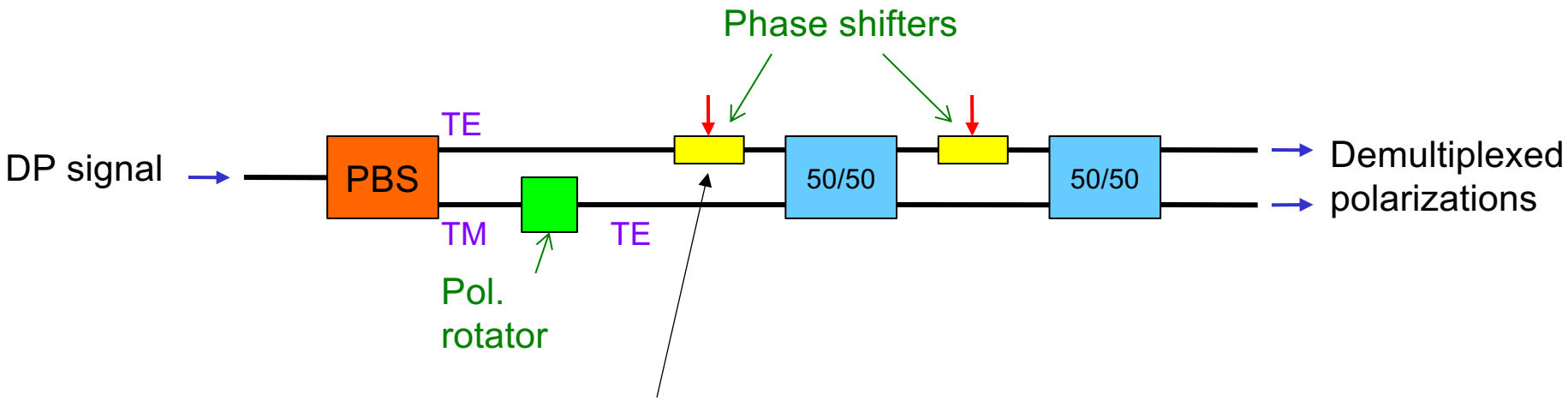
Integrated polarization demultiplexer

In this polarization demultiplexer, the two phase shifters are continuously adjusted as the input polarization changes to maintain the demultiplexing.



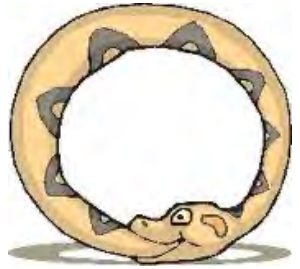
Two phase shifter controls are enough to transfer any input polarization to horizontal or vertical polarization (the other signal will stay orthogonal)

Integrated polarization demultiplexer, cont.

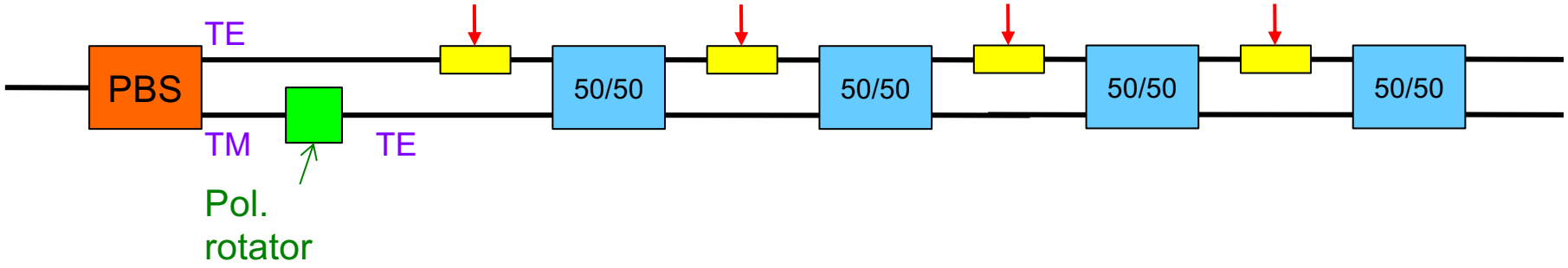


This phase shift requirement is unlimited so will need to reset it, interrupting traffic

Need to make the demultiplexer “endless”



Endless integrated polarization demultiplexer

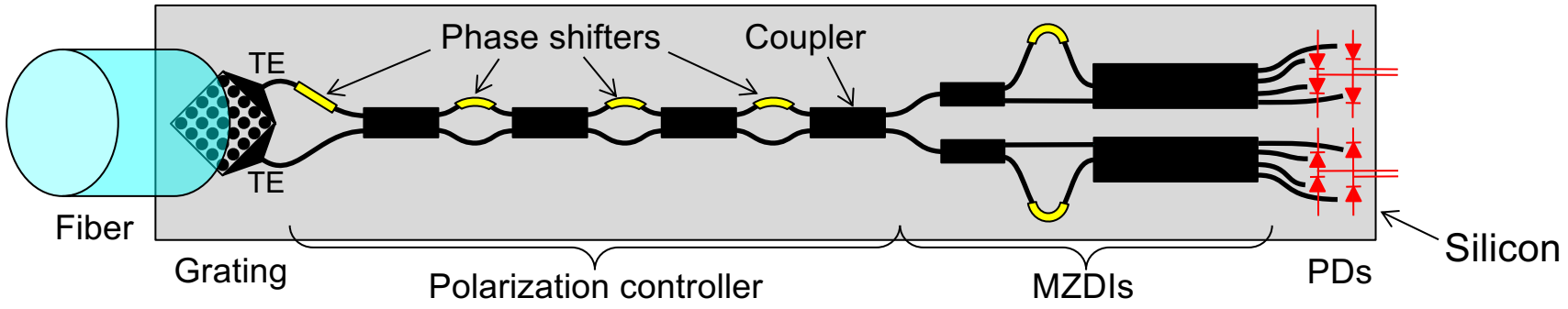


While one phase shifter is resetting gradually back to its center, the other three can keep controlling the polarization

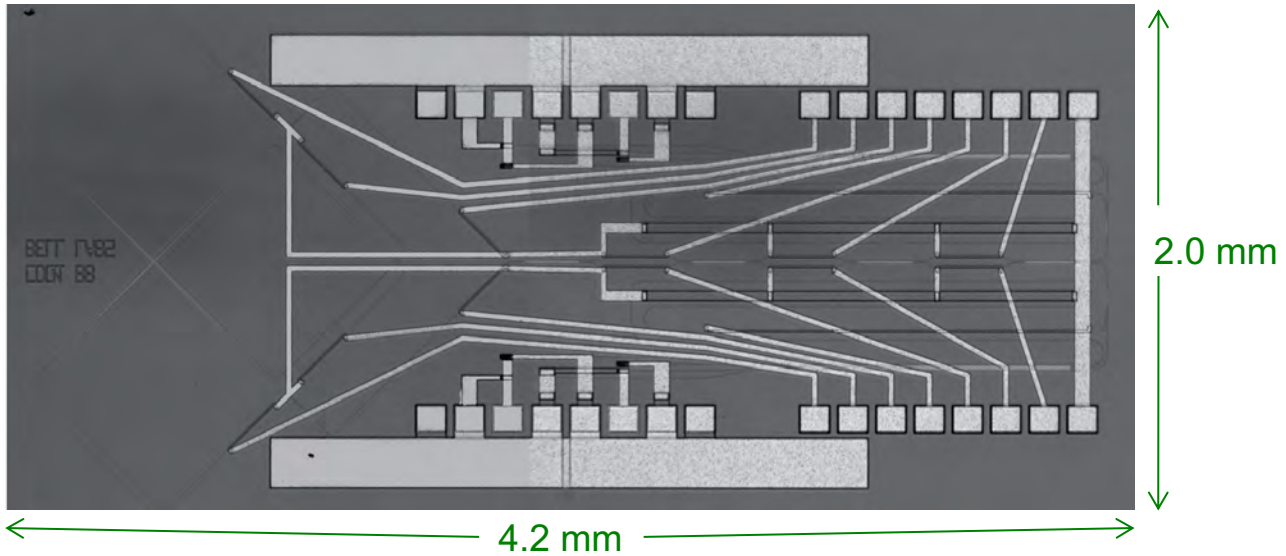
N. G. Walker and G. R. Walker, J. Lightwave Tech., vol 8, pp. 438-458, 1990.

DP-DQPSK SiPh receiver (12 years ago)

This is a DP-DQPSK receiver chip that contains a PBSR, a polarization demultiplexer, and two dual-quadrature Mach-Zehnder delay interferometers (MZDIs) for receiving differential (non-coherent) quadrature phase-shift keying (i.e., each symbol is interfered with the previous symbol in a 90-deg hybrid).



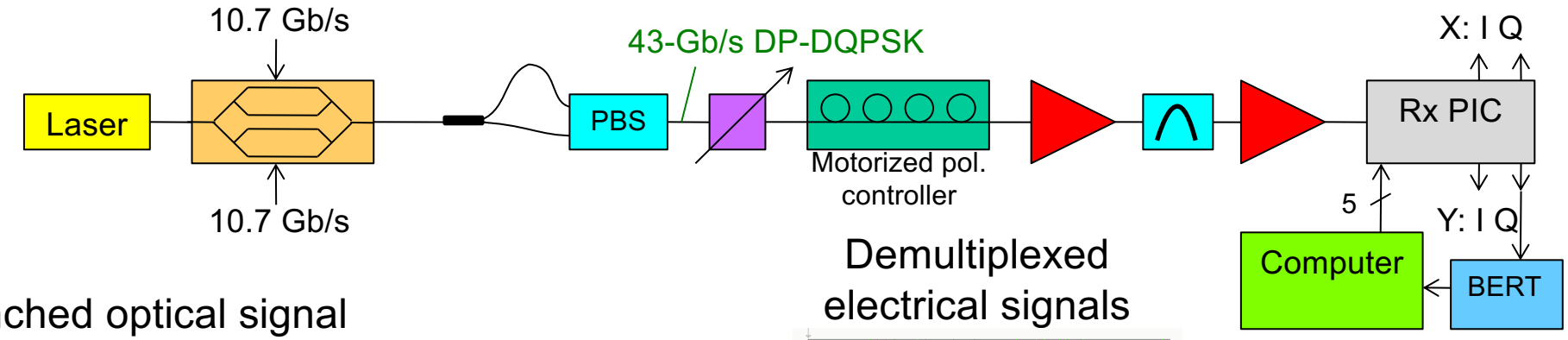
Photograph of the chip



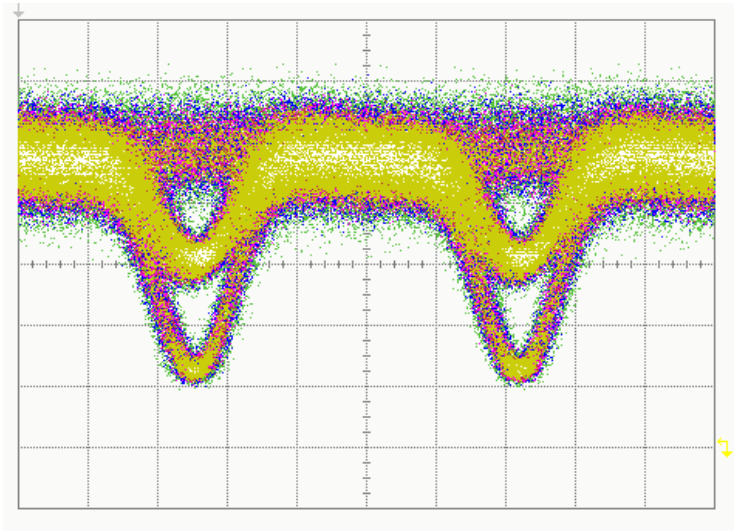
C. Doerr, et al., ECOC, 2010.

System setup for DP-DQPSK experiment

This is the experimental setup for transmitting and receiving 43-Gb/s DP-DPQSK. It consists of an I-Q modulator, a split-delay-and-combine to generate two uncorrelated DQPSK signals, a polarization scrambler, and the receiver. The receiver does the polarization demultiplexing using a feedback loop from the measured BER.



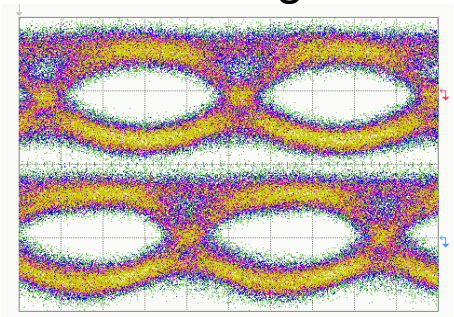
Launched optical signal (one pol.)



10.7 Gbaud (43 Gb/s)

Demultiplexed electrical signals

X pol.

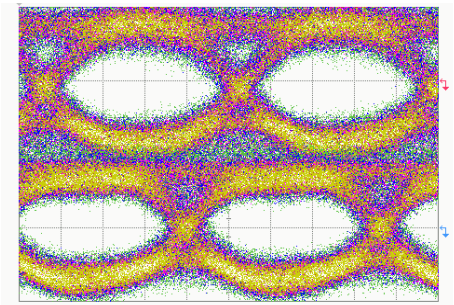


I

Q

(Both polarizations present)

Y pol.

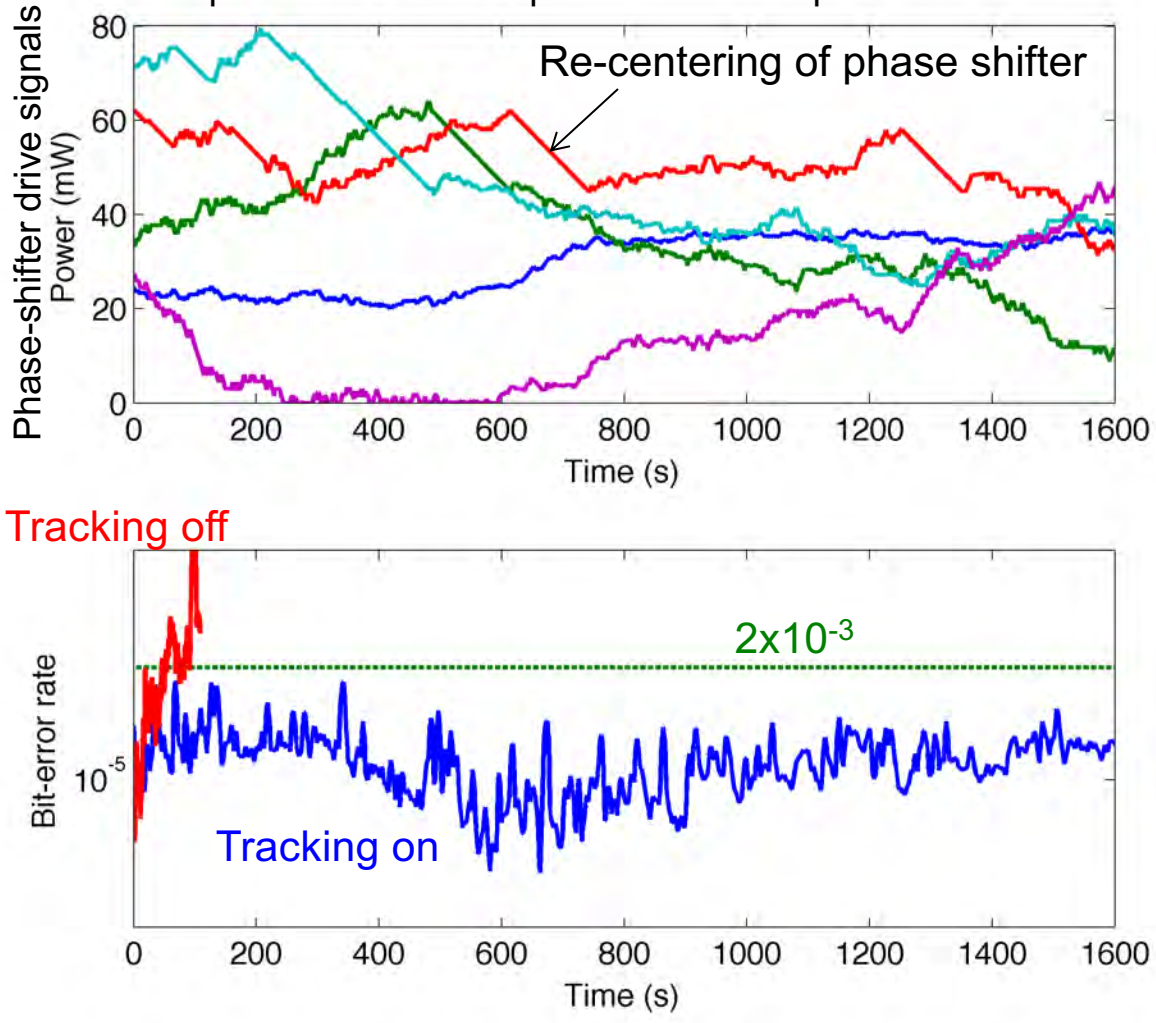


I

Q

Endless polarization tracking demonstration

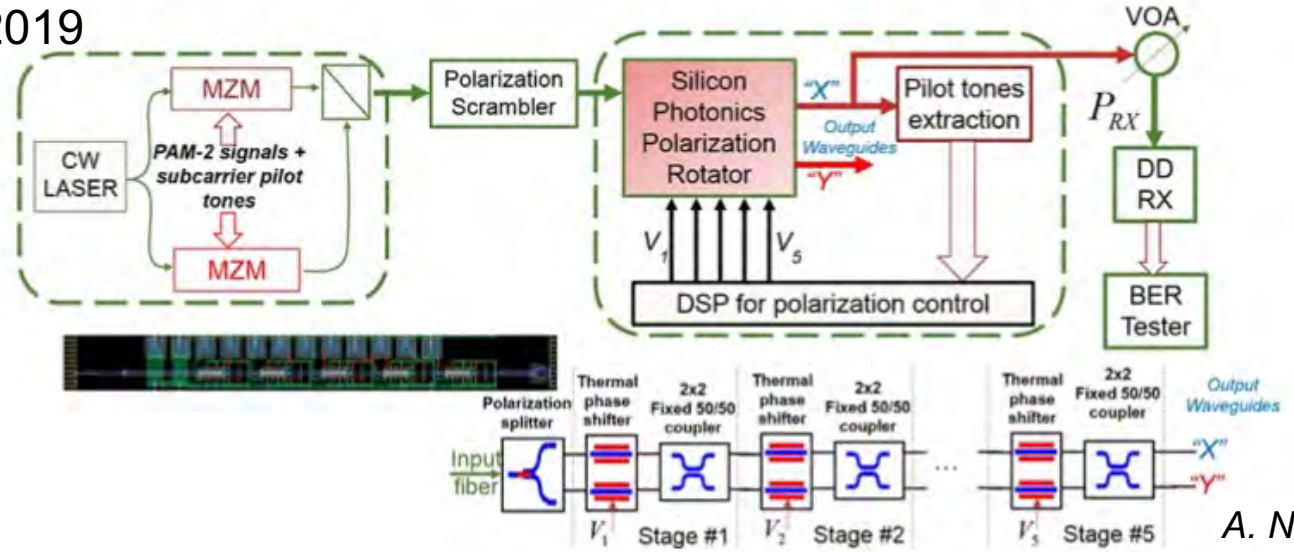
This is data from the 43-Gb/s DP-DQPSK experiment showing the polarization demultiplexer performance as the input polarization is continuously adjusted. The upper plot shows the phase shifter drive signals vs. time, and the bottom plot shows the measured BER vs. time when the polarization demultiplexer control loop is active or frozen.



Feedback is from BER measurement

Recent work by other groups on DP

Cisco 2019



SiPh

A. Nespola, et al., IEEE PTL, pp. 62-65, 2019.

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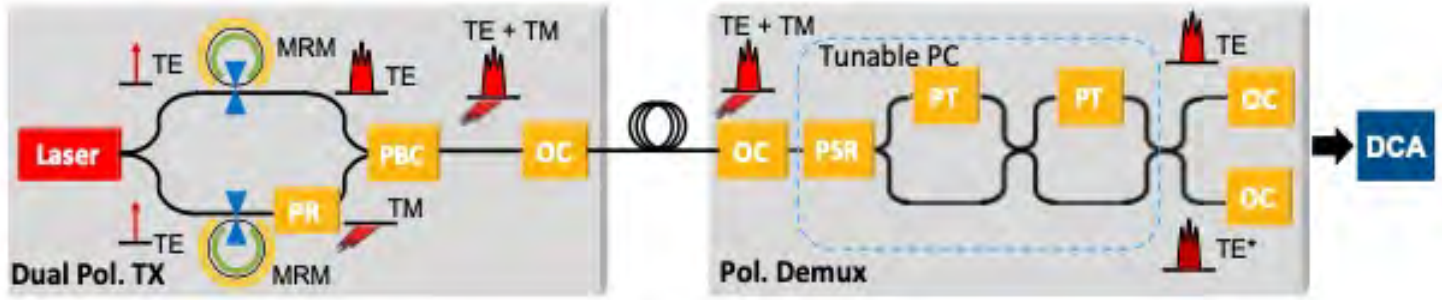
Intel 2021



SiPh

P. Liao, et al., ECOC 2021.

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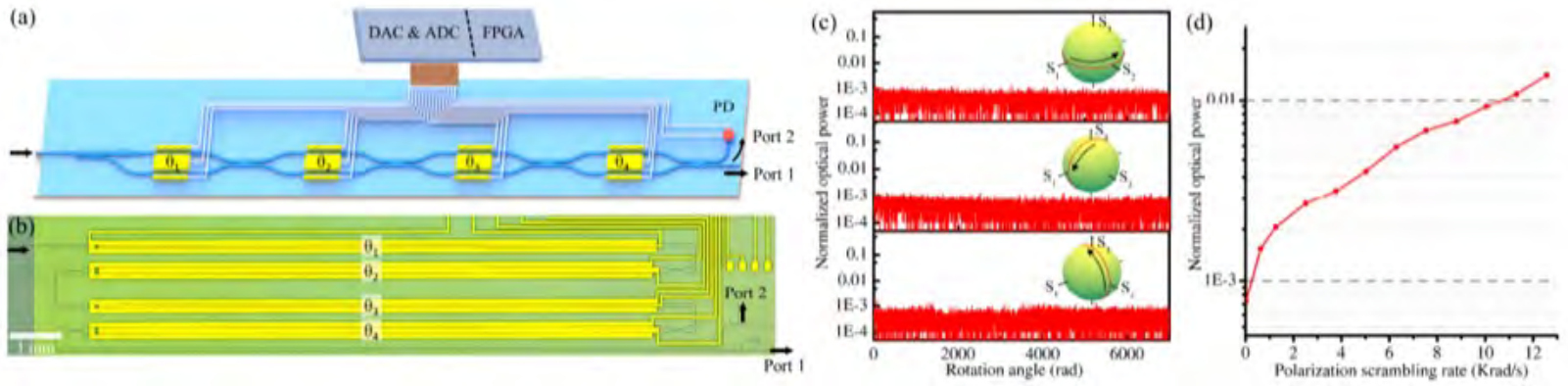
Recent work by other groups on DP, cont.

Sun yat-sen Univ. 2022



TFLN

Z. Lin, et al., OFC, paper Th1D.5, 2022.

Reprintable because this is considered an IEEE publication.

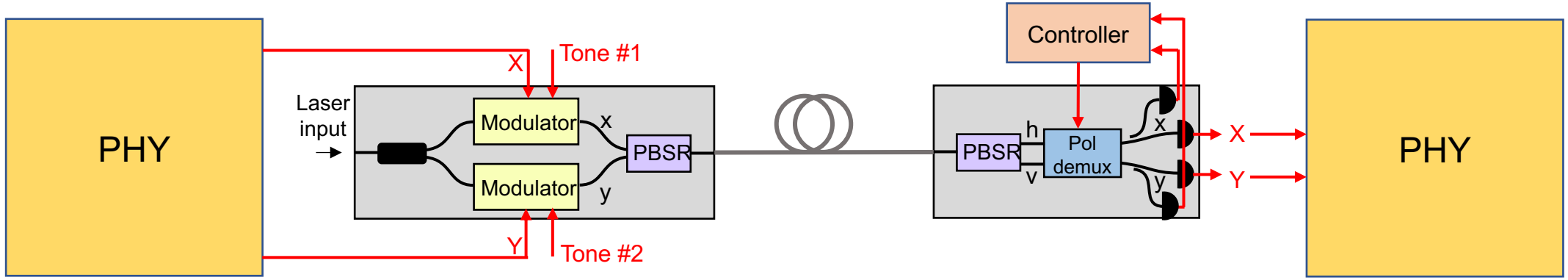
Futurewei 2020

4-stage polarization demultiplexer (single polarization for coherent LO)

SiPh

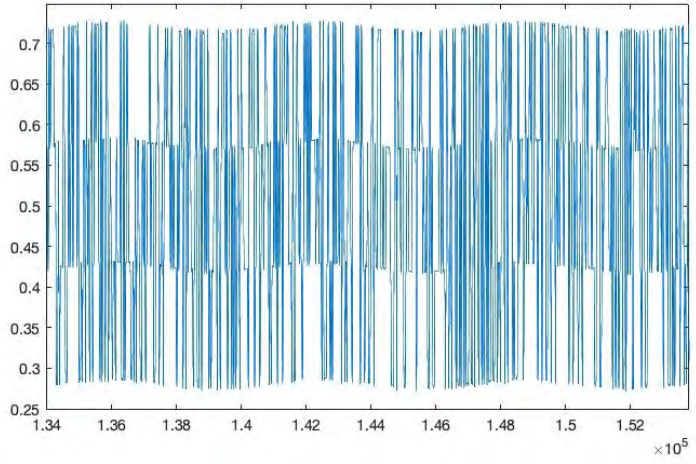
Y. J. Wen, et al., Opt. Exp., paper 397047, 2020.

DP-PAM4 simulation: setup

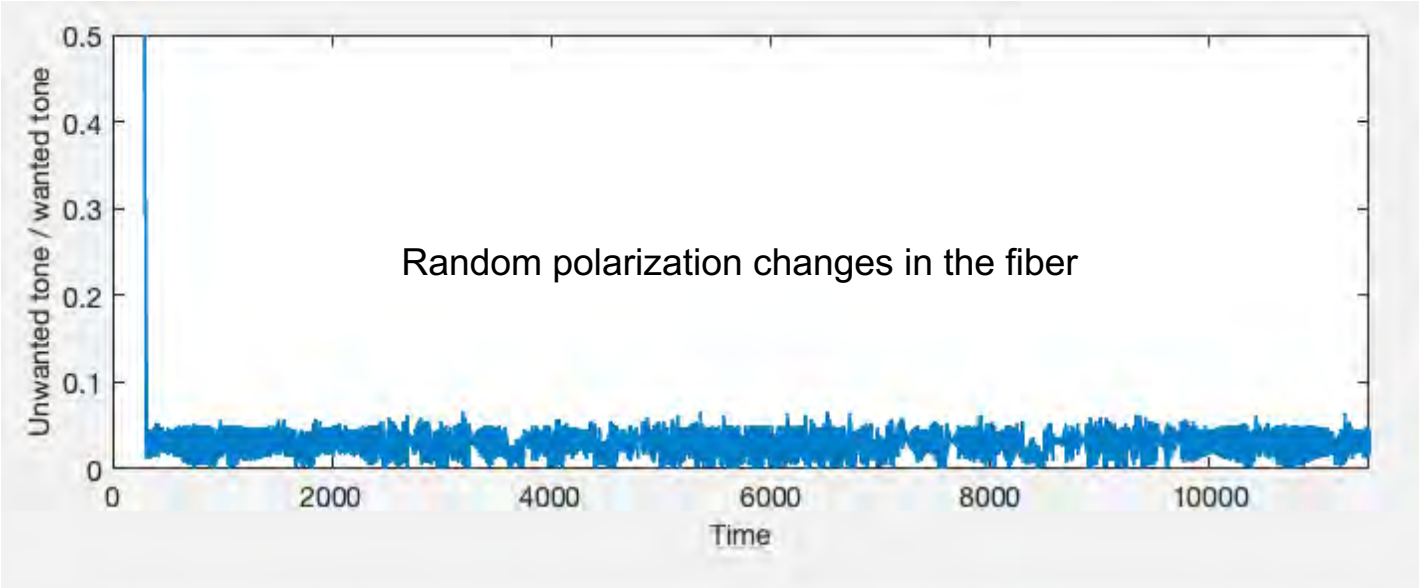


- Endless demultiplexing
- Demultiplexing is self-contained
  - No PHY interaction required
  - Backward compatible (at half net rate)

PAM4 optical signal with added 2% tone

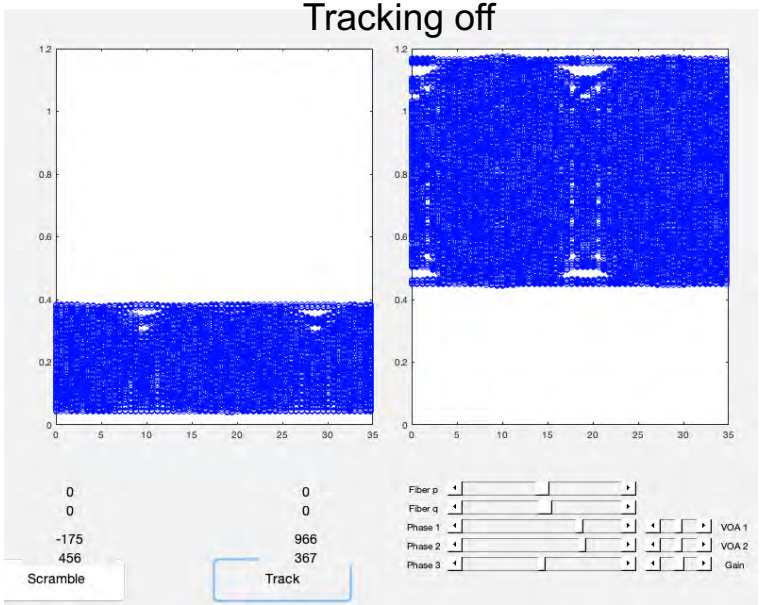


DP-PAM4 simulation: results

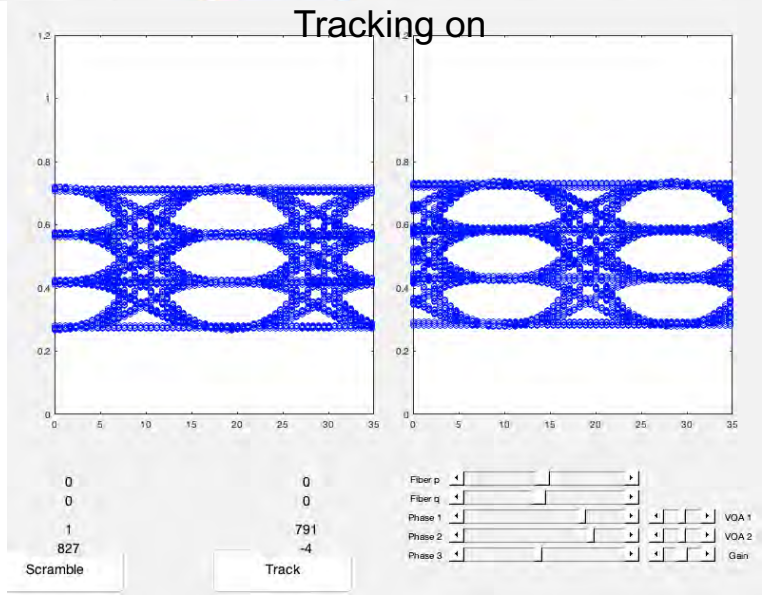


Random polarization changes in the fiber

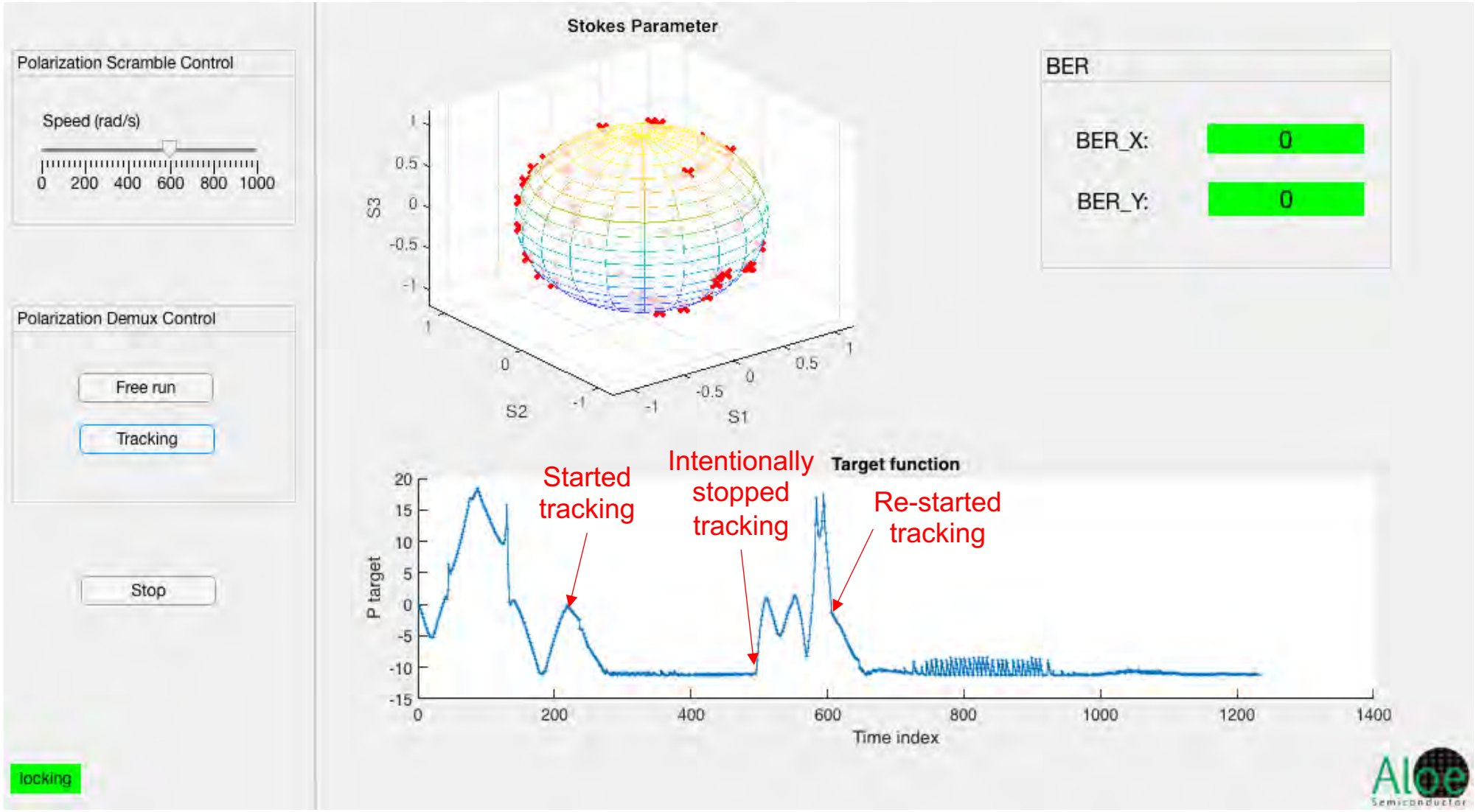
Tracking off



Tracking on

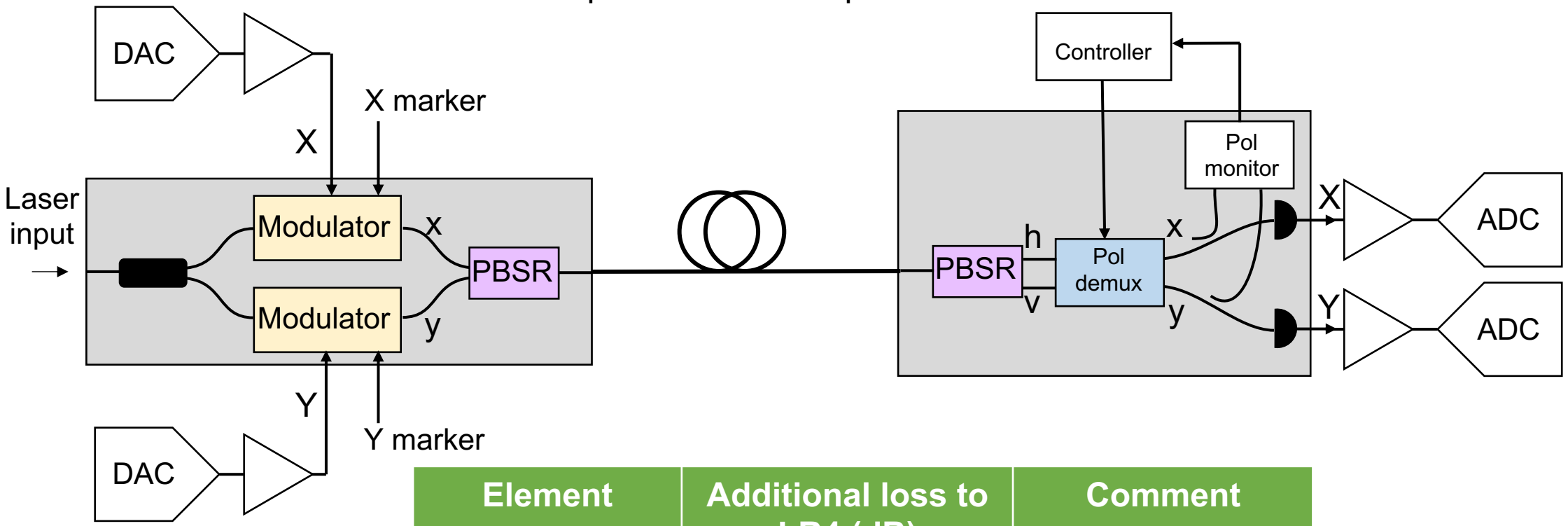


DP-PAM4 simulation: more results



Link budget

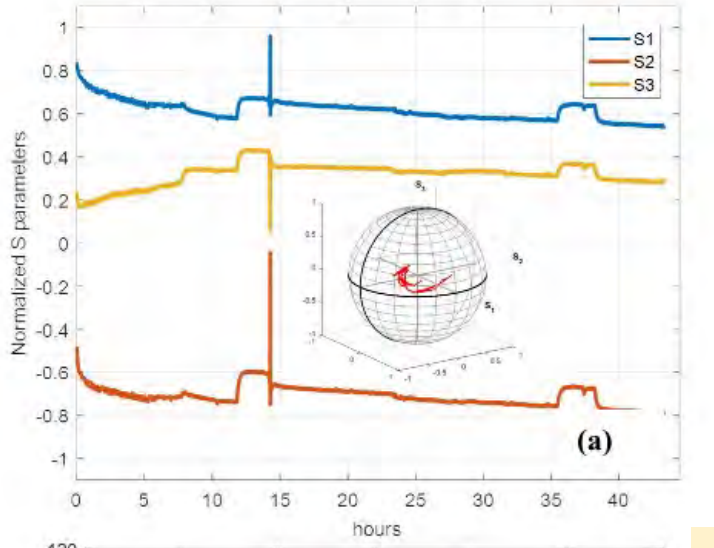
Assumptions
Loss of PBSR and use of TM: ~0.6 dB
Loss of pol demux and taps: ~0.6 dB

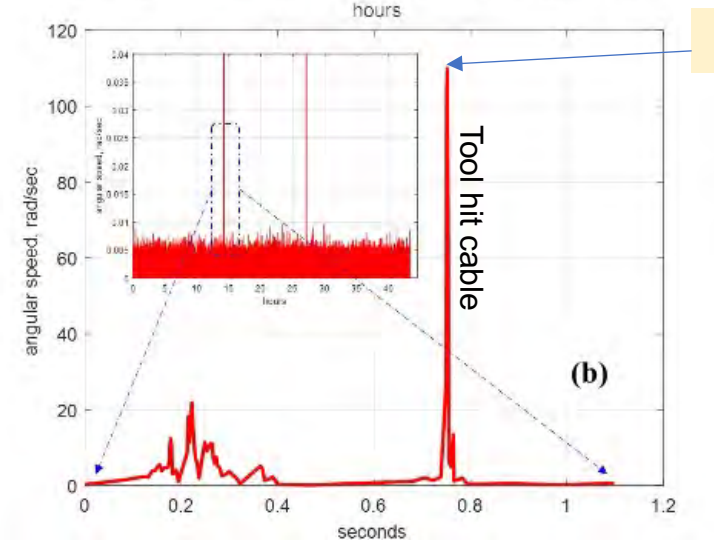


Element	Additional loss to LR4 (dB)	Comment
Tx	~3.6	Increase in required laser power
Rx	~1.2	Increase in required sensitivity (per lane)

Required polarization tracking speed

1.3 km in data center





110 rad/s

A. Nespola, et al., IEEE PTL, pp. 62-65, 2019.

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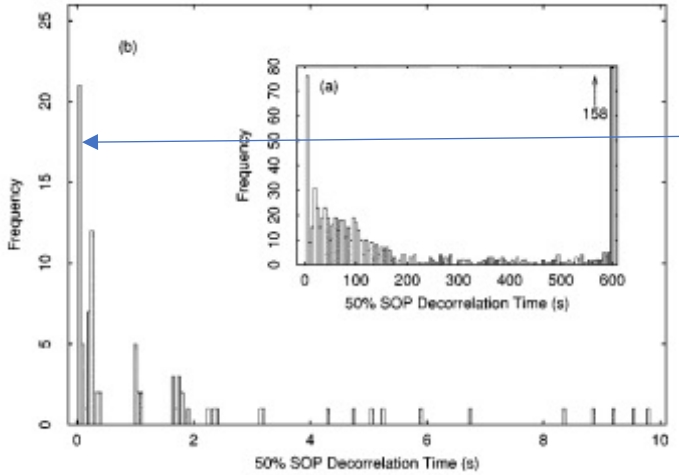
34 km aerial cable



~100 rad/s

D. S. Waddy, et al., IEEE PTL, pp. 1035-1037, 2001.

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LRM tracking requirement is 10 Hz (802.3aq clause 68)

Note coherent ZR spec.: 50 krad/s

Initially propose spec. of 200 rad/s max for LR

Conclusions

- DP-PAM4 800G LR4 works with existing 100G PAM4 PHY and only requires
  - Simple analog MIMO control
  - Standard IM-DD laser except ~3.6 dB higher power than LR4
  - Half the laser quantity
- DP is backward compatible with existing 400Gbase-LR4-6
- DP-PAM4 doubles bit rate with roadmap to IM-DD 400G single λ
- Some next steps
  - Measure polarization change rates in real LR links
  - Penalty from marker tones, if any
  - Fiber nonlinearity effects on DP
  - Detailed link budget analysis
  - Further control simulations and experimental demonstrations.