Low Voltage Differentially Signaled Silicon Resonant Modulators

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William A. Zortman, Anthony L. Lentine
Douglas C. Trotter, Ralph W. Young and Michael R. Watts*
wzortm@sandia.gov

Sandia National Labs Albuquerque, NM
Applied Photonic Microsystems

*Massachusetts Institute of Technology
Research Laboratory for Electronics

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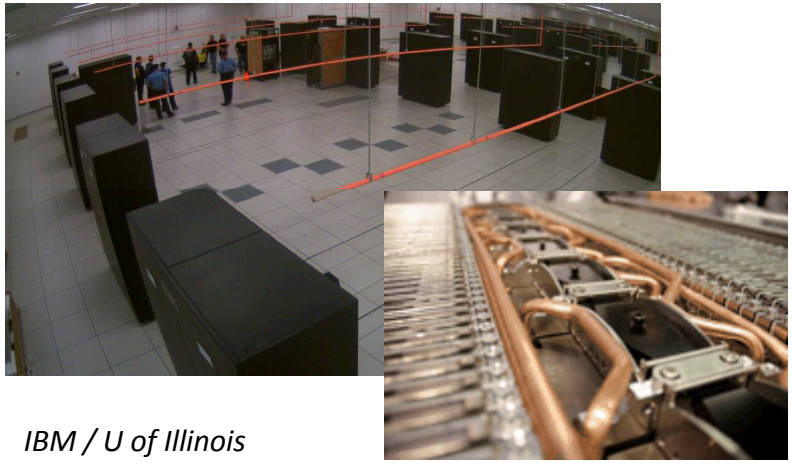
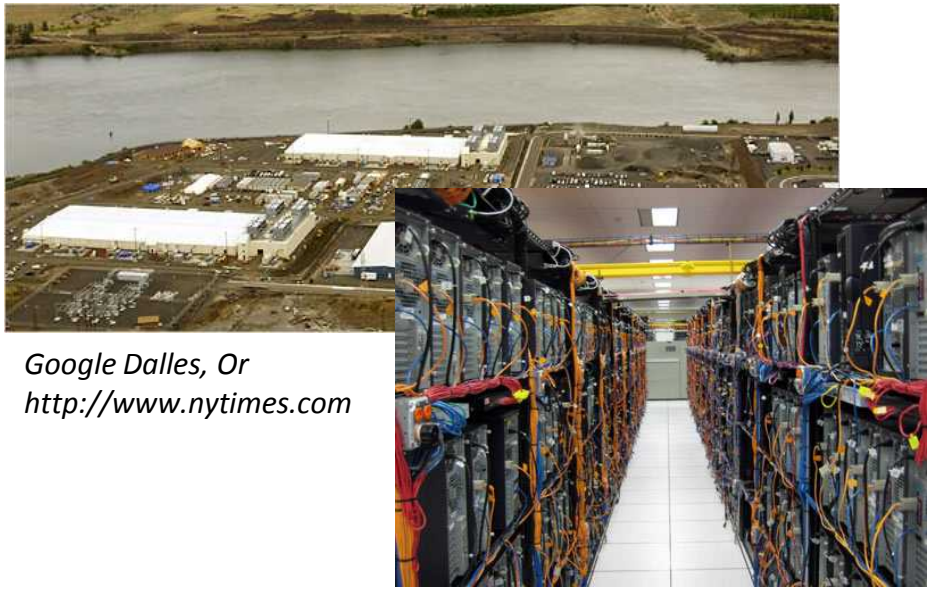
Supercomputer



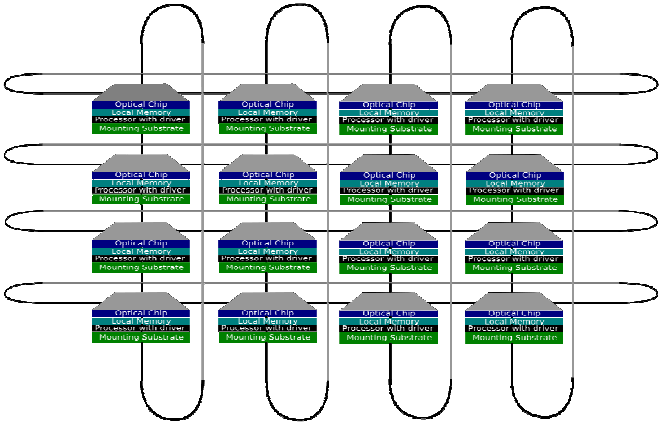
IBM / U of Illinois
Blue Waters, http://www.ncsa.illinois.edu/BlueWaters

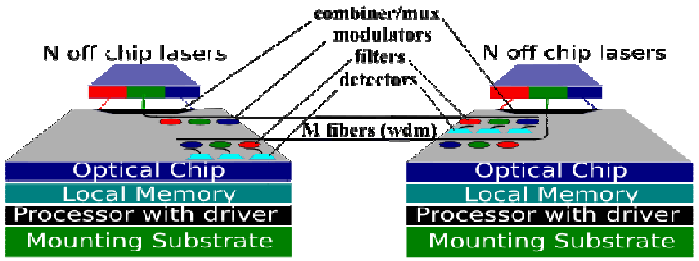
Data Center



Google Dalles, Or
http://www.nytimes.com

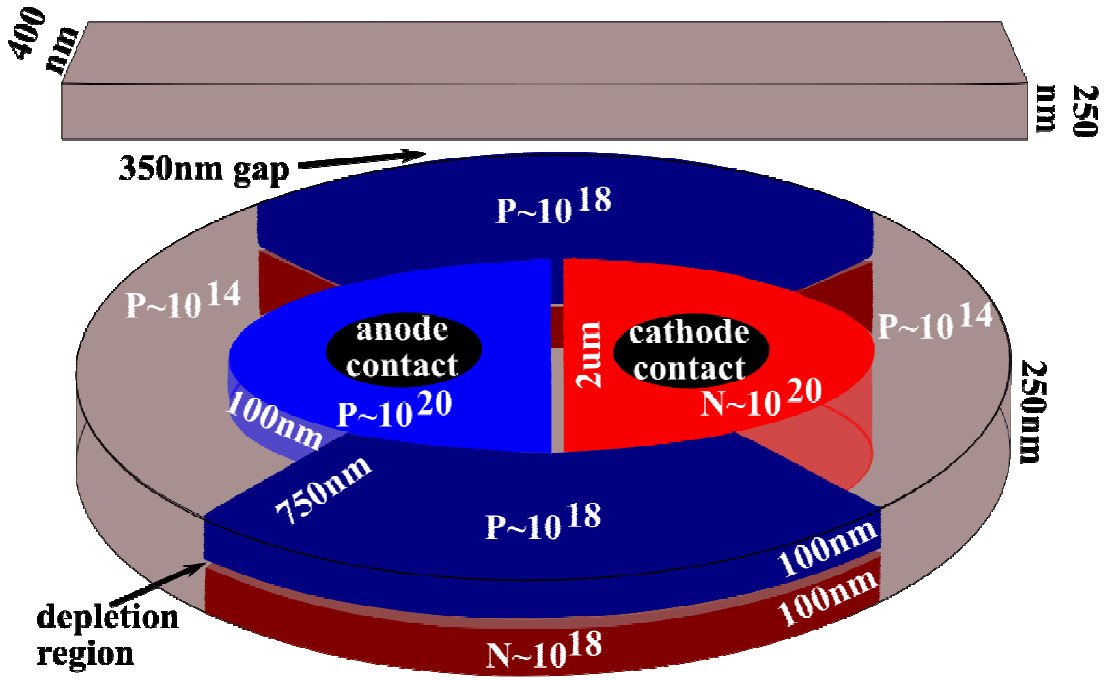
http://scienceblogs.com

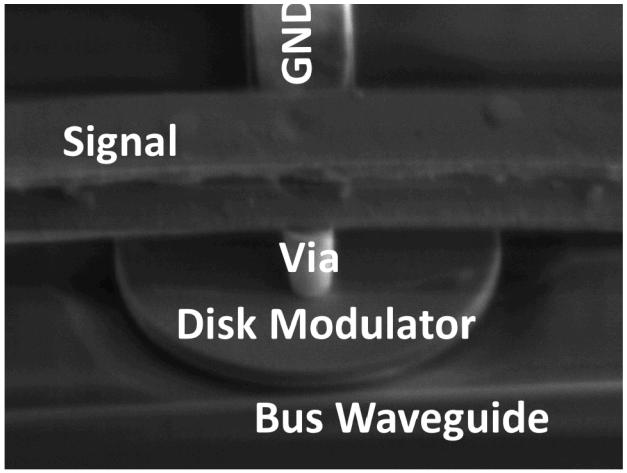


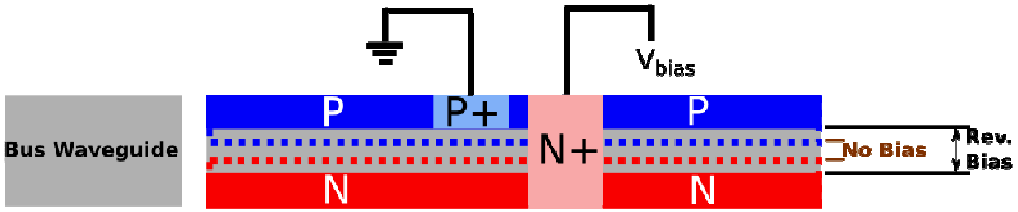


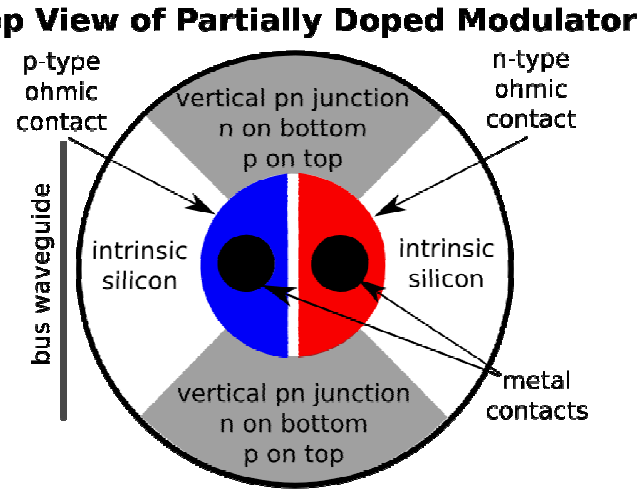
These systems could likely run with electrical interconnect or continue with parallel multimode optics, however WDM waveguide integration offers BW and system simplicity advantages

Architecture of the modulator for today's talk









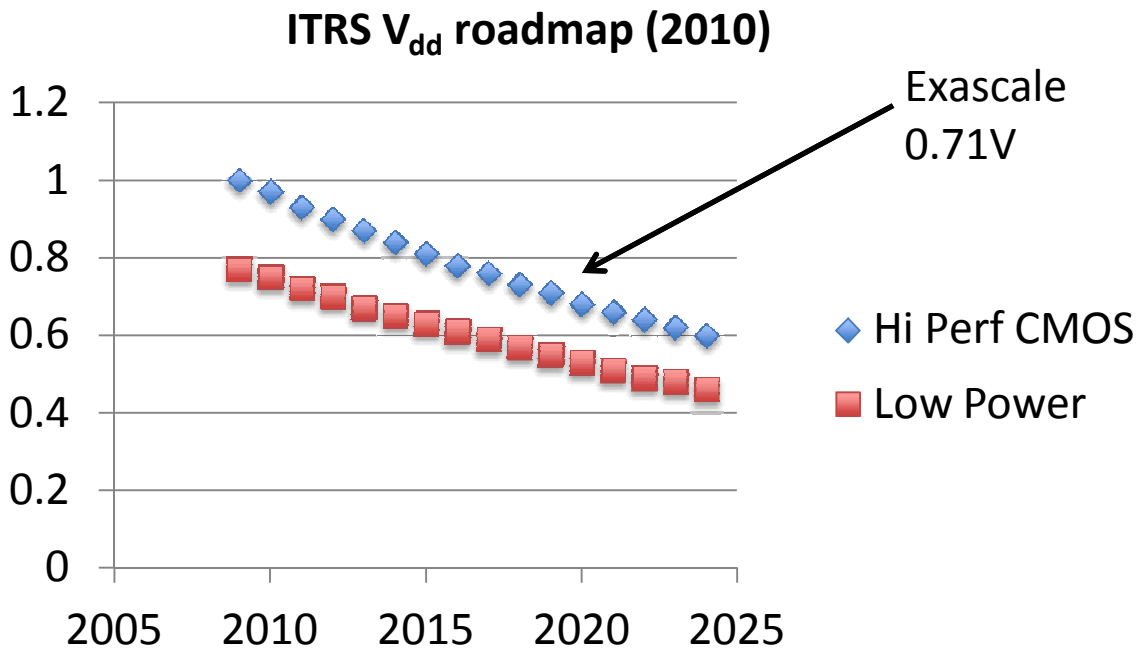
3.5 micron diameter

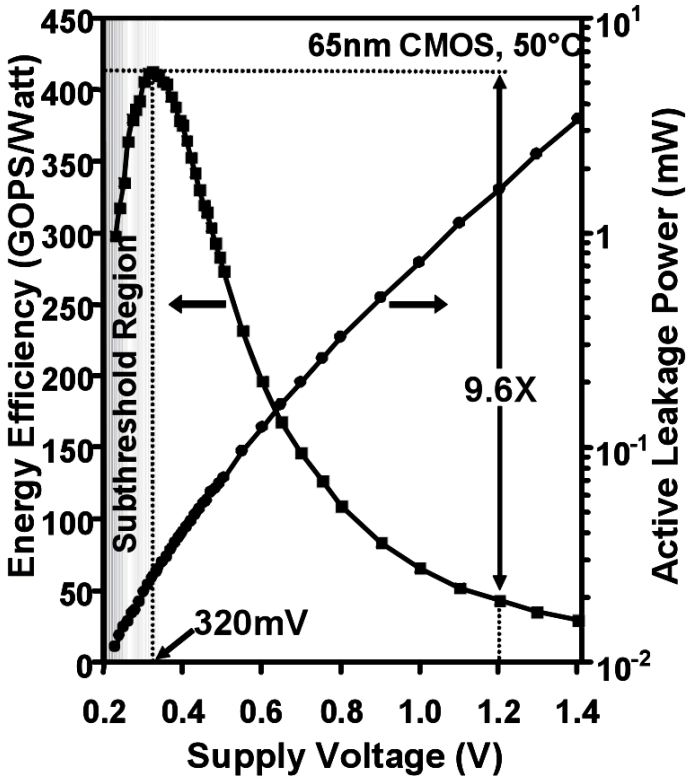
Silicon on Insulator 250nm thick silicon on 3µm buried oxide

5µm deposited oxide over the device and waveguide

operates in reverse bias

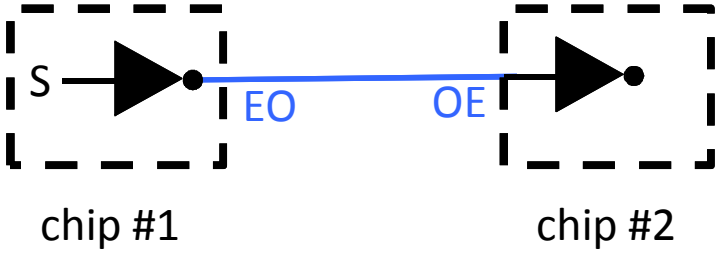
Motivation for low voltage photonics





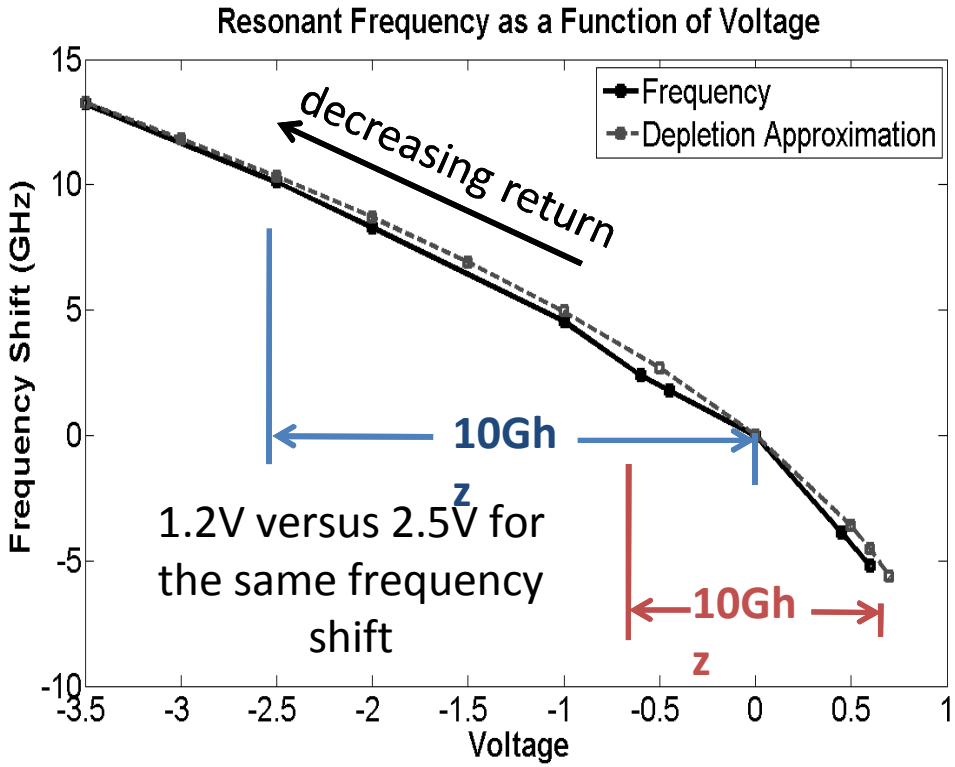
from Shekhar Borkhar, "The Exascale Challenge"

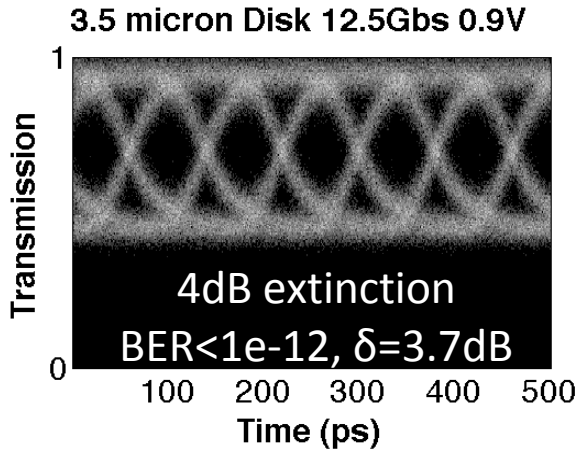
Ideally this situation is desired:

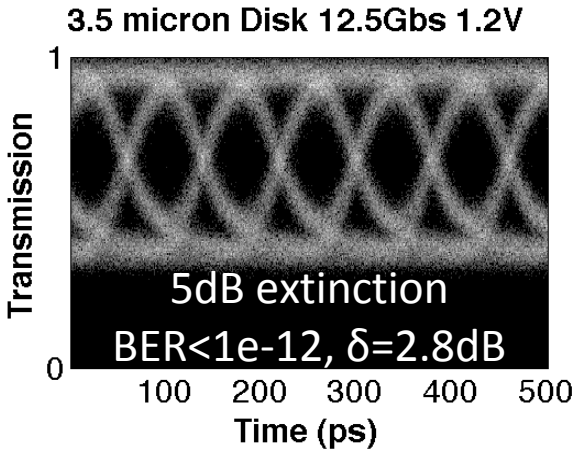


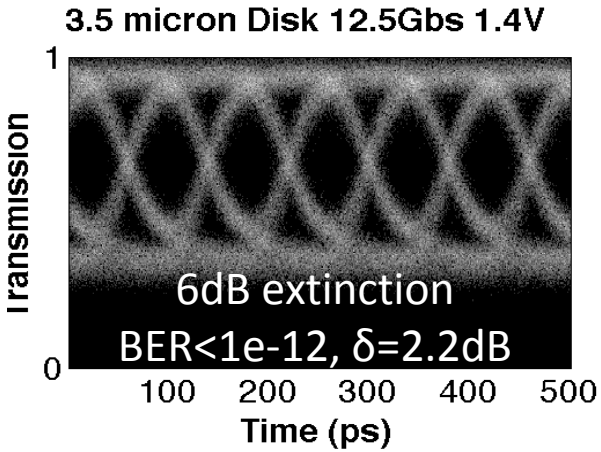
Differential signaling would ease integration with the potential for much lower V_{dd}

AC coupling of drive signal





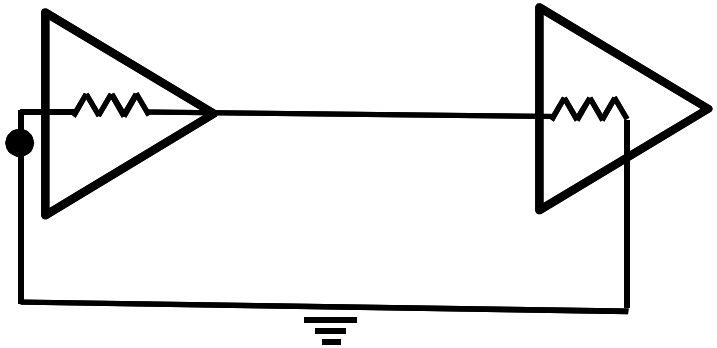


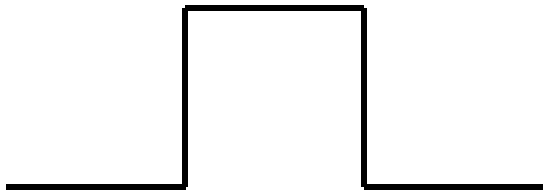


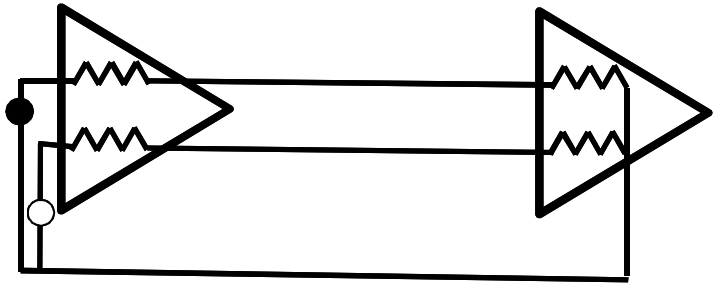
Energy/bit:	**0.9V**	**1.2V**	**1.4V**
Analysis:	**3.8fJ/bit**	**6.8fJ/bit**	**10.6fJ/bit**
Measured:	**3.2fJ/bit@1V**		**10.1fJ/bit@1.5V**

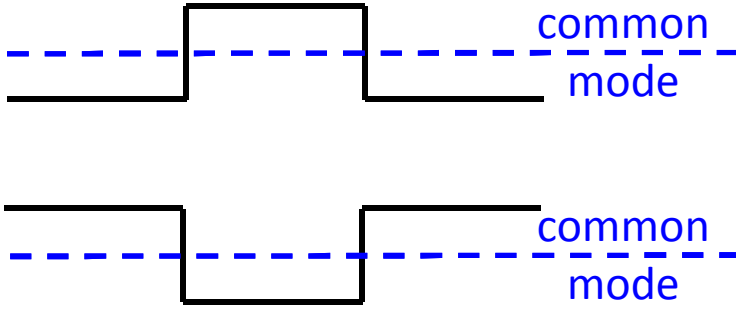
Zortman, Watts, Trotter, Young, Lentine, CLEO, 2010

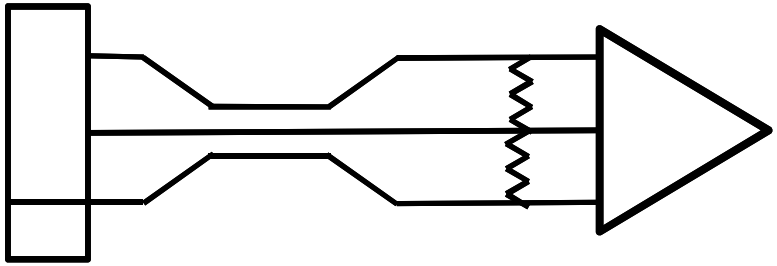
For even lower voltage drivers: differential signaling is considered for driving the device











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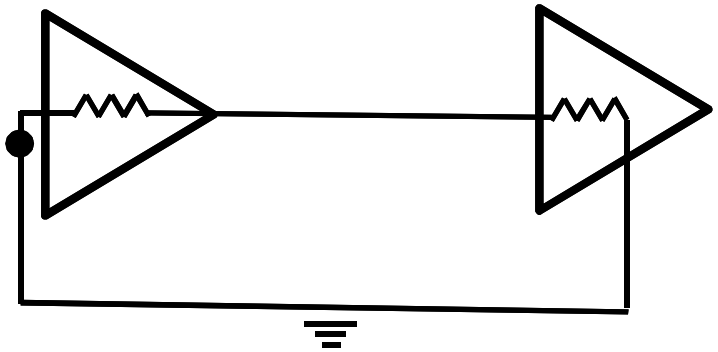
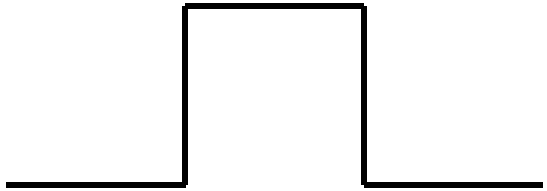
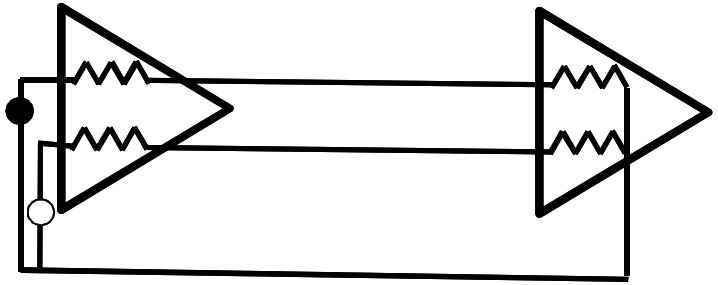
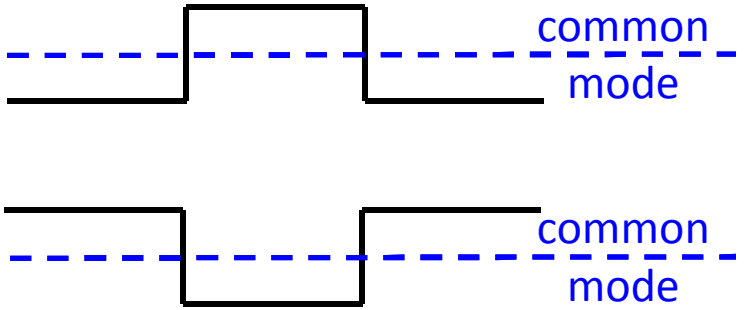
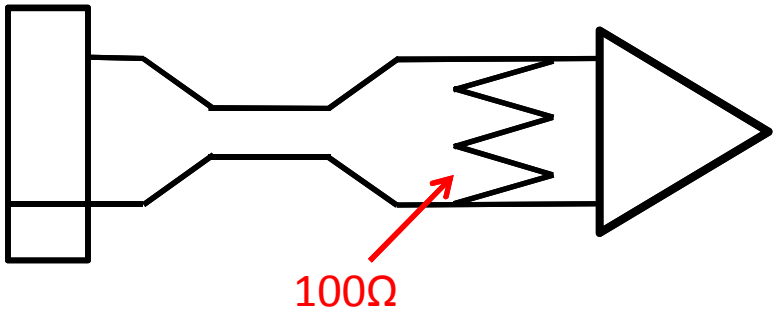






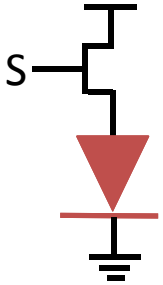




Forward Bias

high current driver

CMOS



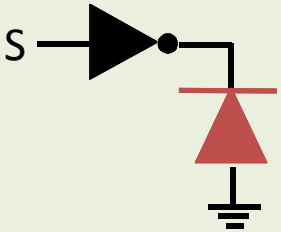
Xu et al, origina
Manipatruni et al CLEO

~1 PJ/bit
V_{dd}=V

LVDS

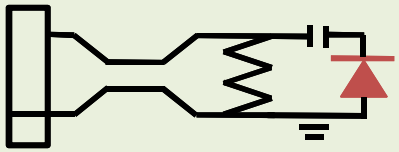
Reverse Bias

high voltage driver

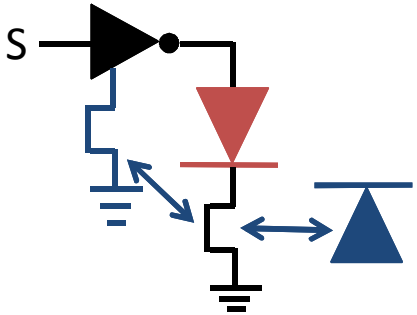


Wattts et al Gp 4 2008
Dong et al OPEX 2009

~50fJ/bit
V_{dd}=3.5V



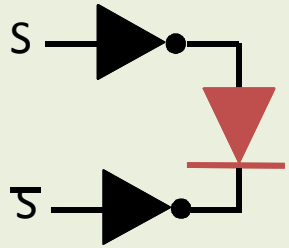
AC Coupling



Zortman, Watts et al CLEO 2010
Watts et al OPEX 2011
Dong et al OL 2010
Glenn et al OPEX 2011

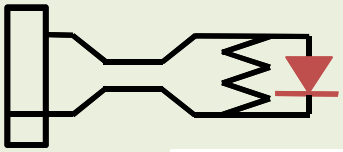
3fJ/bit
V_{dd}=1V

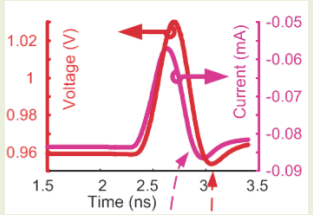
Differential Signaling



This Work

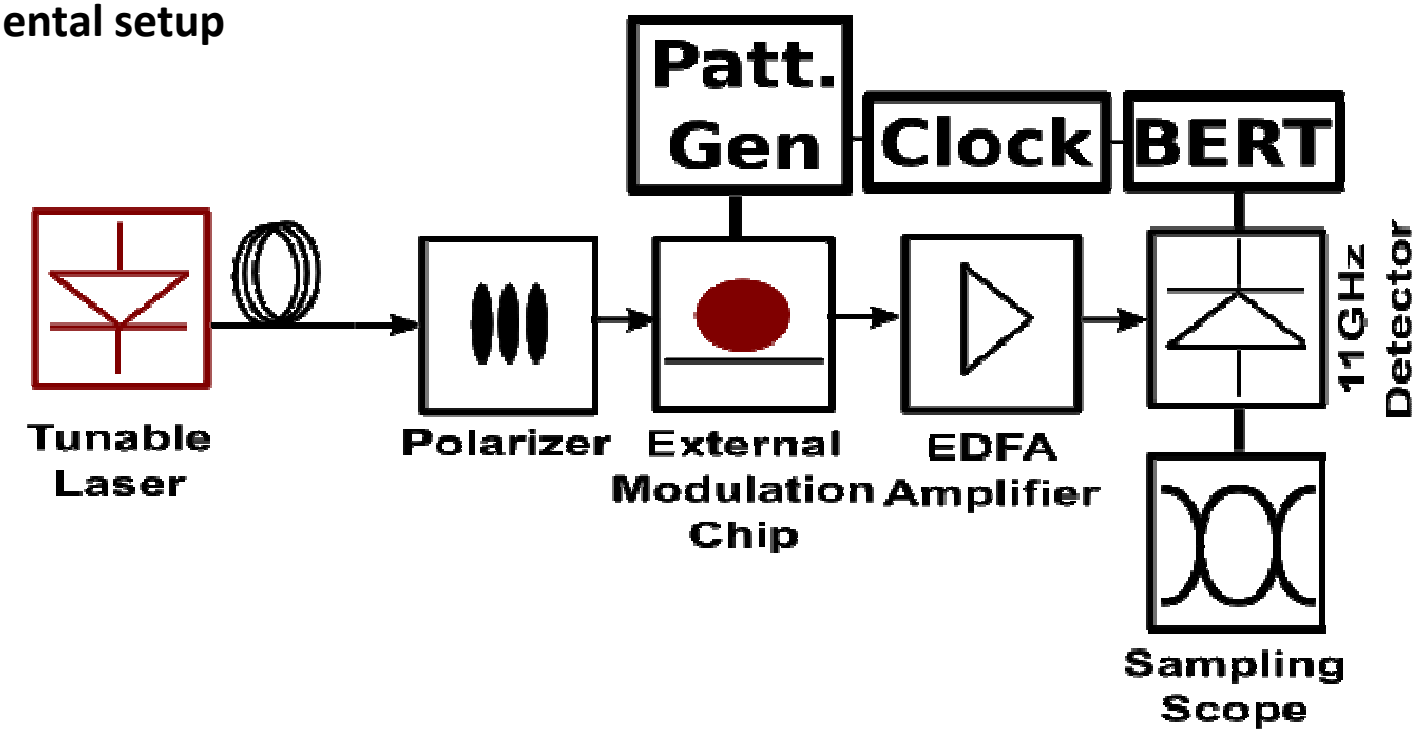
3fJ/bit
V_{dd}=500mV



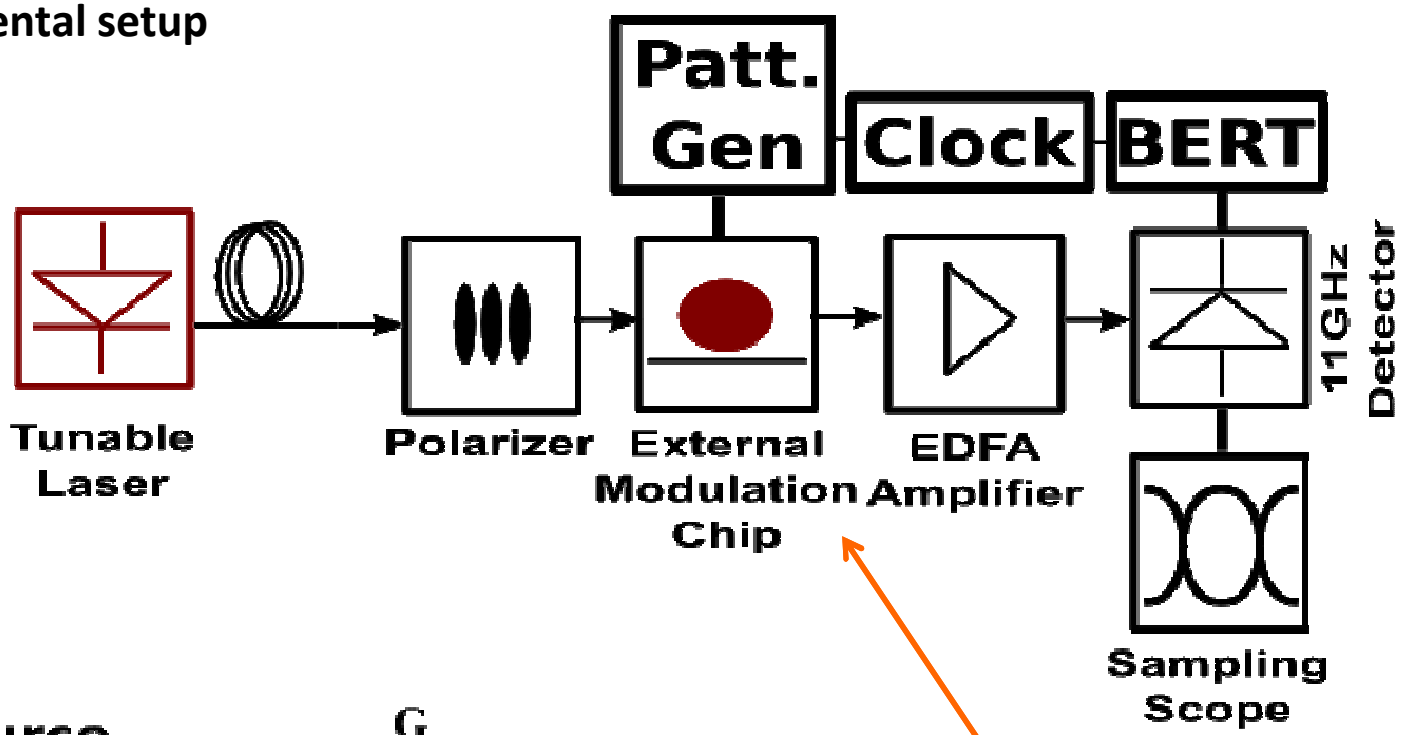


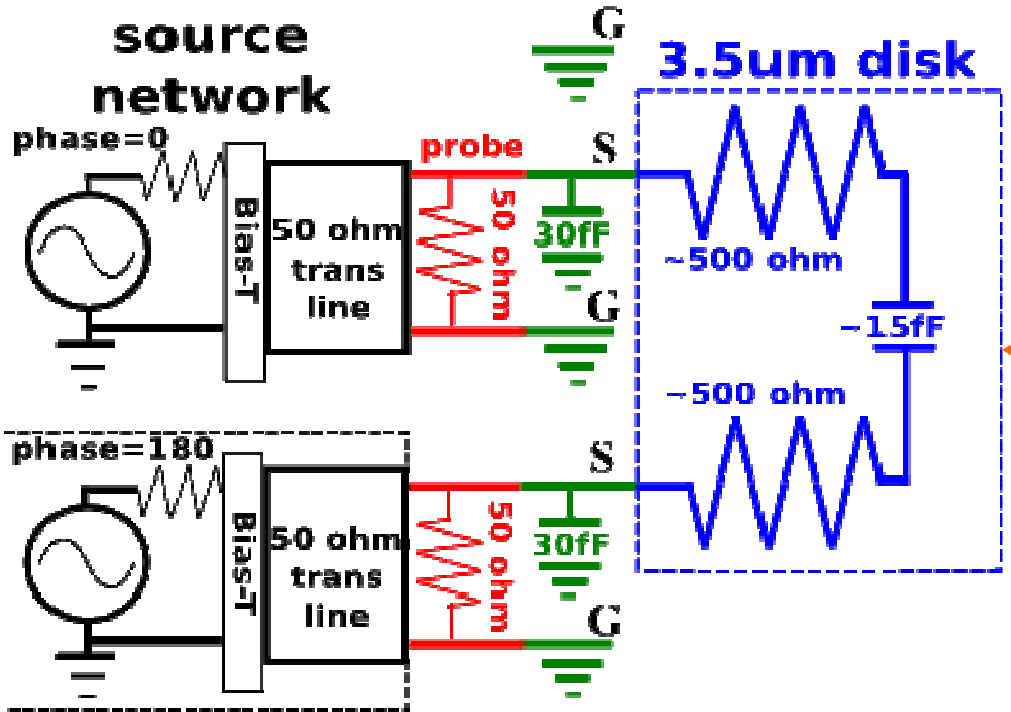
356fJ/bit 90nm 4Gbps CMOS LVDS
Kim, Stojanovic ISSCC 2009

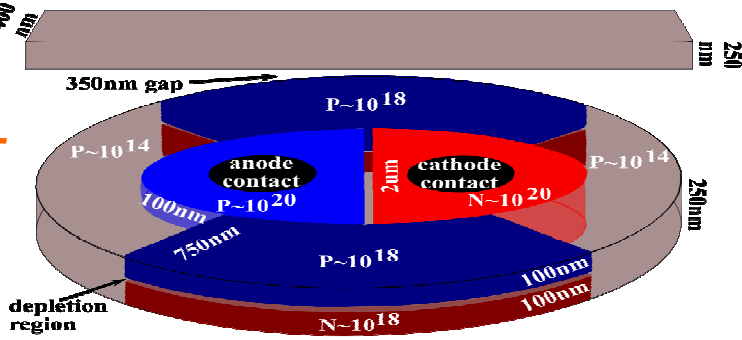
Experimental setup



Experimental setup

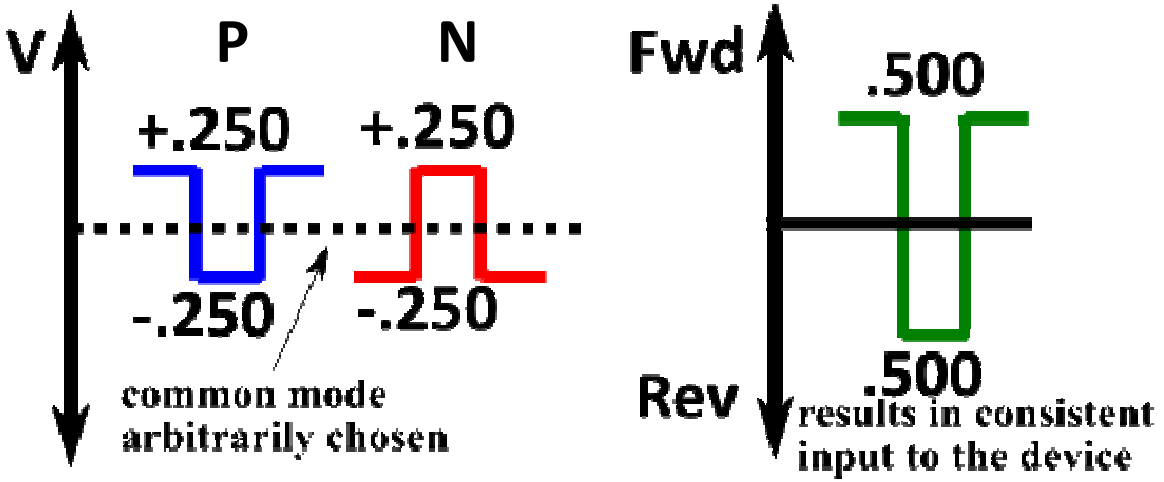




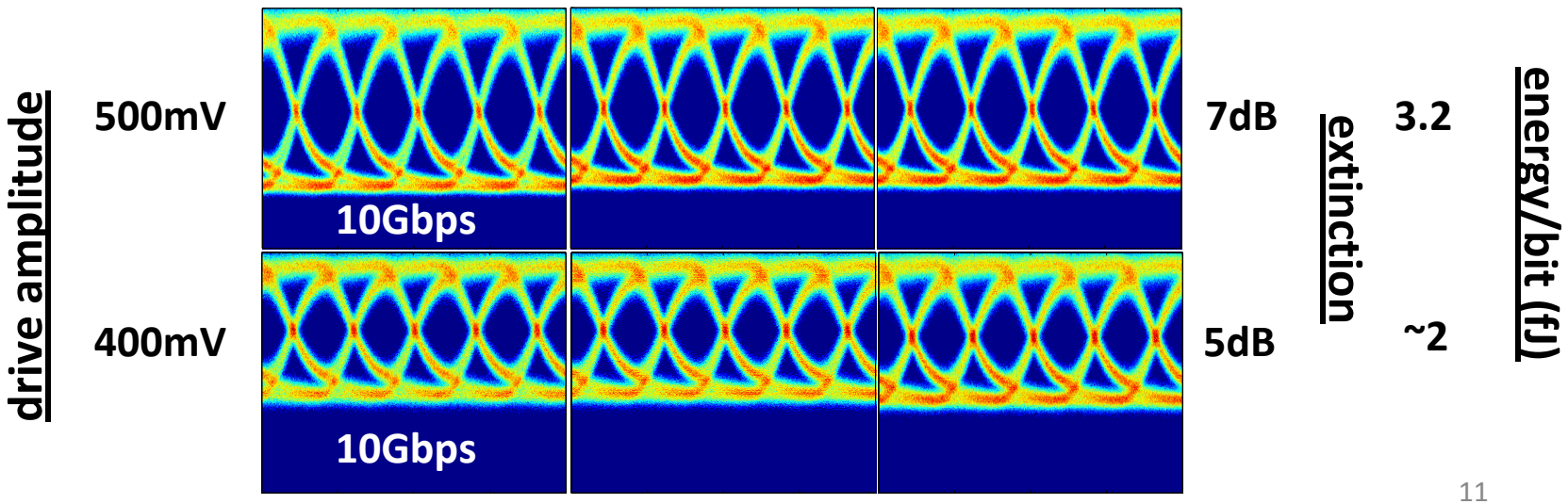


The easiest to implement is symmetric differential signaling

… the common modes are the same and the BER $<10^{-12}$



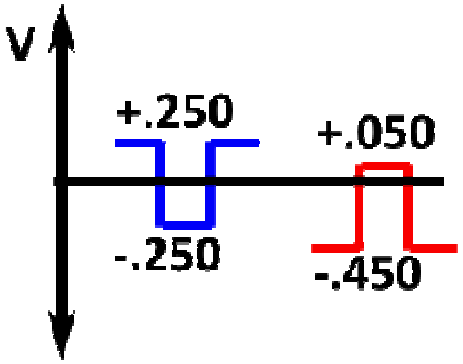
common modes (AC or DC coupling)

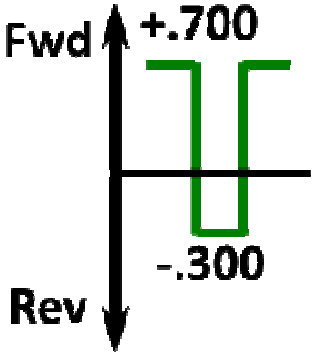


Assymetric signaling is a larger challenge

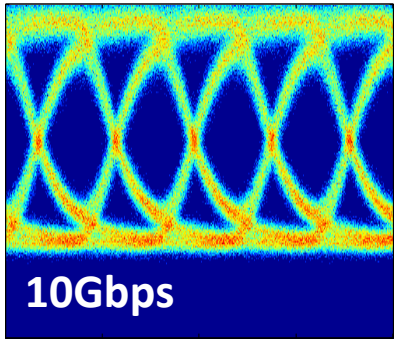
… the common modes are different and can require negative drive

however this allows drive into forward bias and a slight increase in extinction ratio for a given V

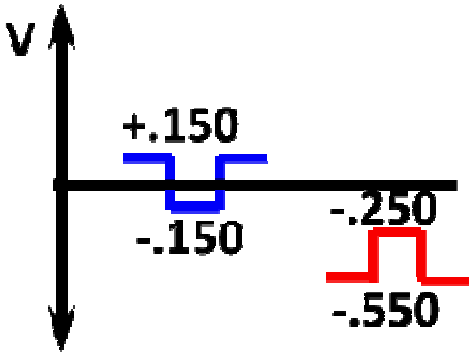


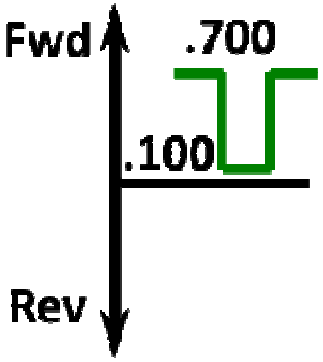


500mV

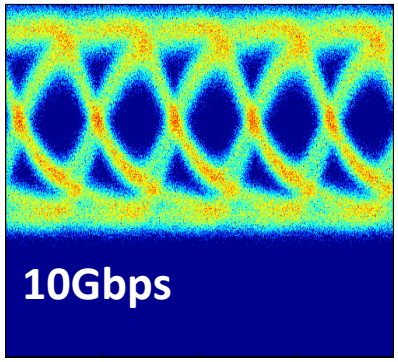


7dB

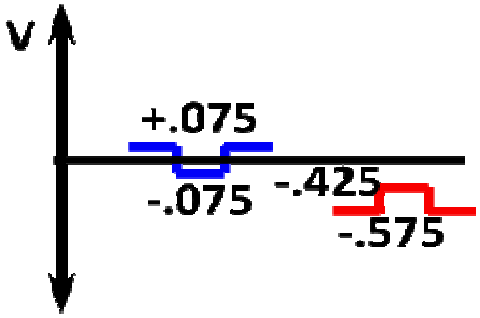


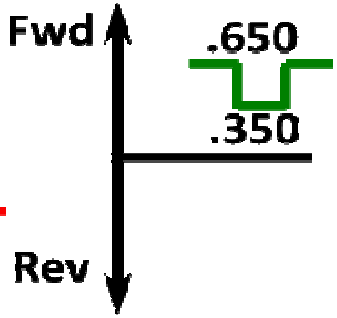


300mV

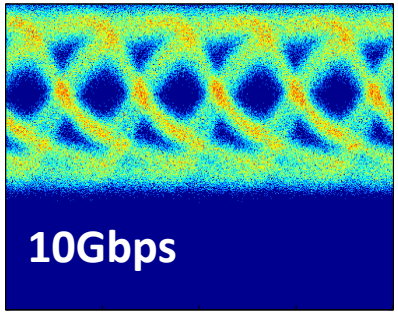


5dB





150mV



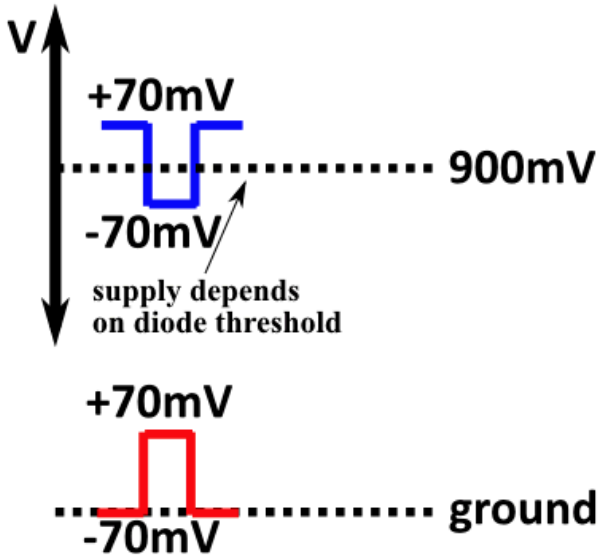
4dB

Forward bias differential signaling

This requires a DC current, however the voltages to swing are very low

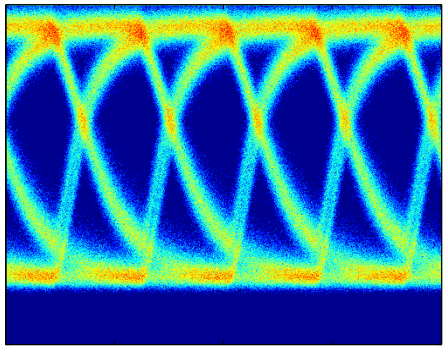
We find that going beyond 2^7-1 PRBS with BER<10^{-12} is not possible due to resistive heating

This would require fan-out to a larger driver because $V_{I,sat}$ is forecast to be ~350mV

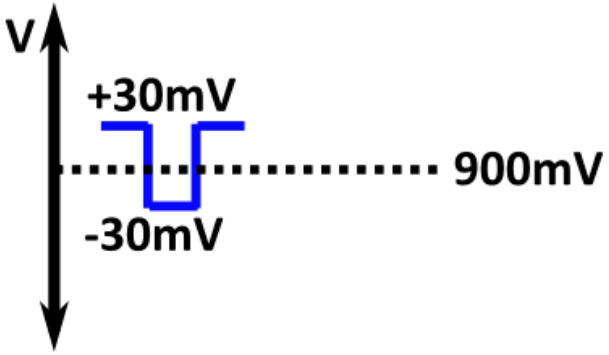


1Gbps

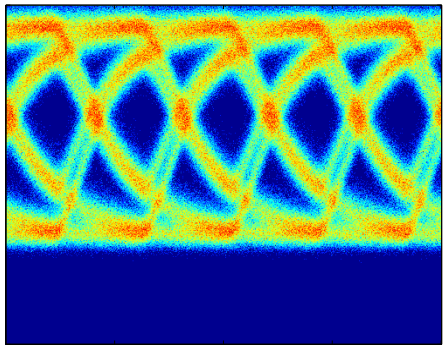
70mV



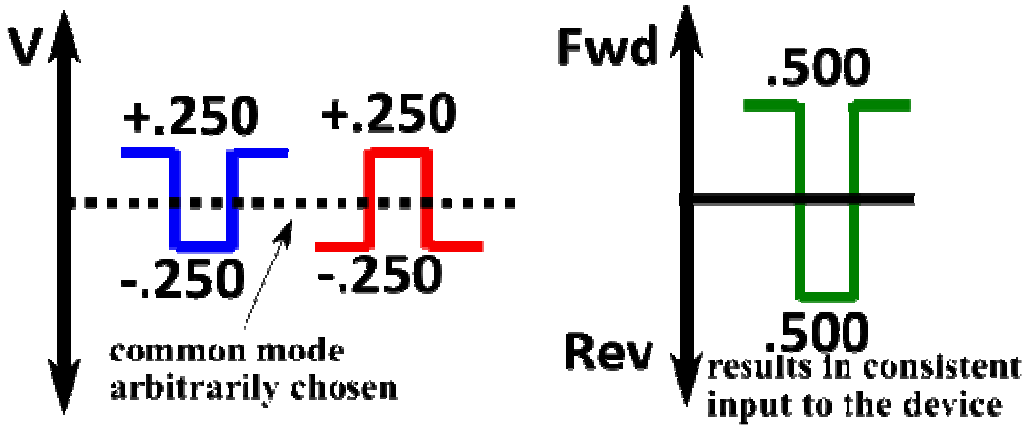
7dB



30mV



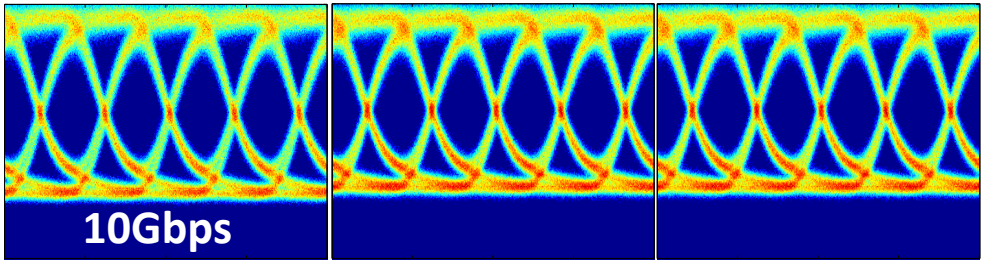
5dB



common modes (AC or DC coupling)

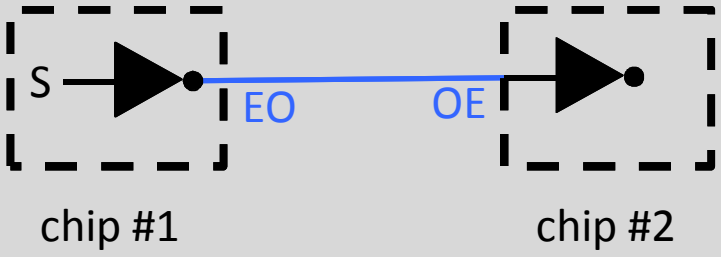
0V **1.25V** **1.5V**

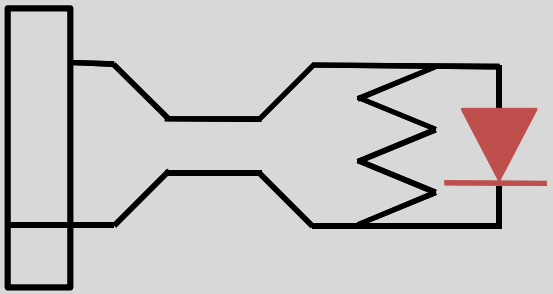
500mV



7dB ext. **3.2fJ/bit**

Compatible with LVCMOS, VCL, CML, LVDS and requires *no special drivers*





Conclusion

Advantages of Differential Signaling for Silicon Photonics

Broadens the design space

Direct interface to LVDS

Compatibility with future V_{dd} scaling

Works with $V_{applied}/2$

New Capabilities Demonstrated

BER < 1e-12 with 150mV supply and <1fJ/bit (asymmetric)
with 400mV supply and ~2fJ/bit (symmetric)

Questions

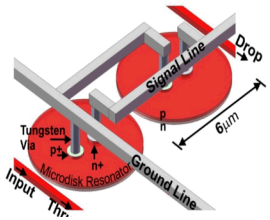
William A. Zortman, Anthony L. Lentine, Douglas C. Trotter, Ralph W. Young and Michael R. Watts
wzortm@sandia.gov

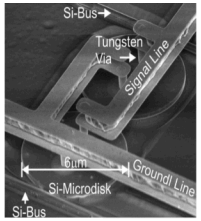
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

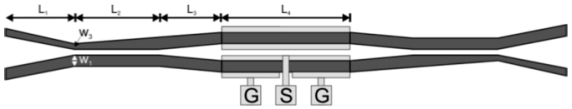
NNSA National Nuclear Security Administration

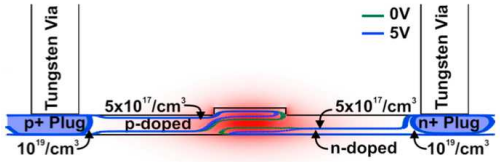
LDRD

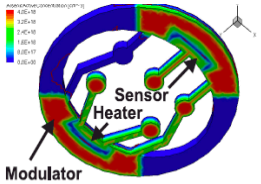
Sandia National Laboratories

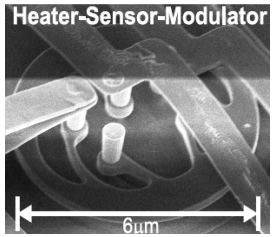


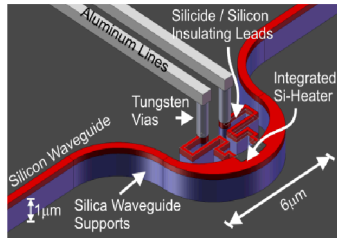


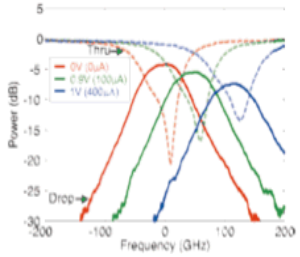


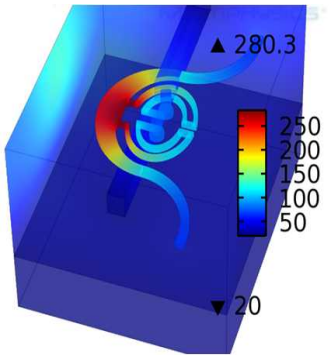


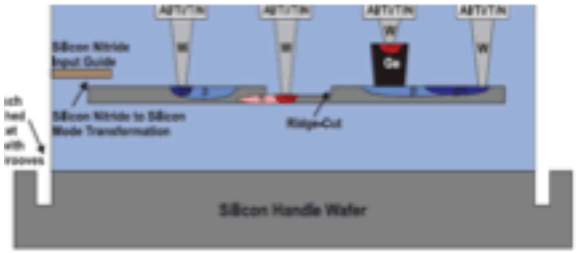


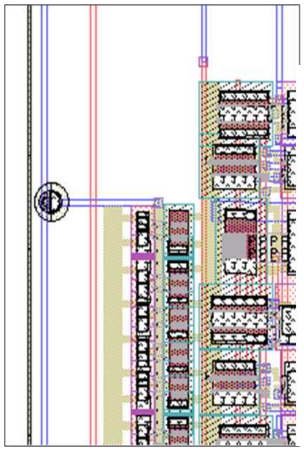




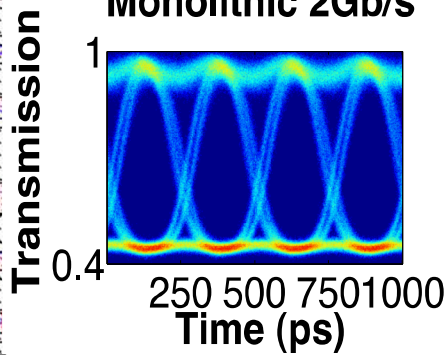








Monolithic 2Gb/s



Ge Detector 10 Gbps