



Why Si Photonics?

Rent's Rule

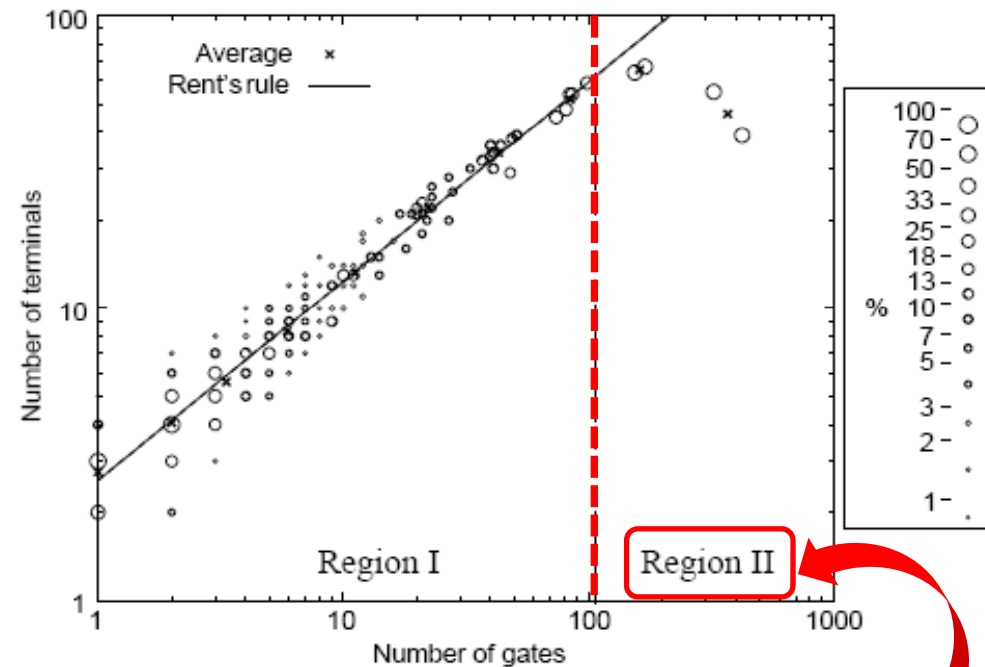
- Predict the number of pins in a logic block

Ref. P. Christie, *T. VLSI*, 2002

$$T = t \times g^p$$

- T – number of pins
- t – constant
- g – number of logic gates
- p – rent exponent

System type	Rent exponent (p)
Static memory	0.12
Microprocessor	0.45
Gate array	0.50
High-speed computer	0.63

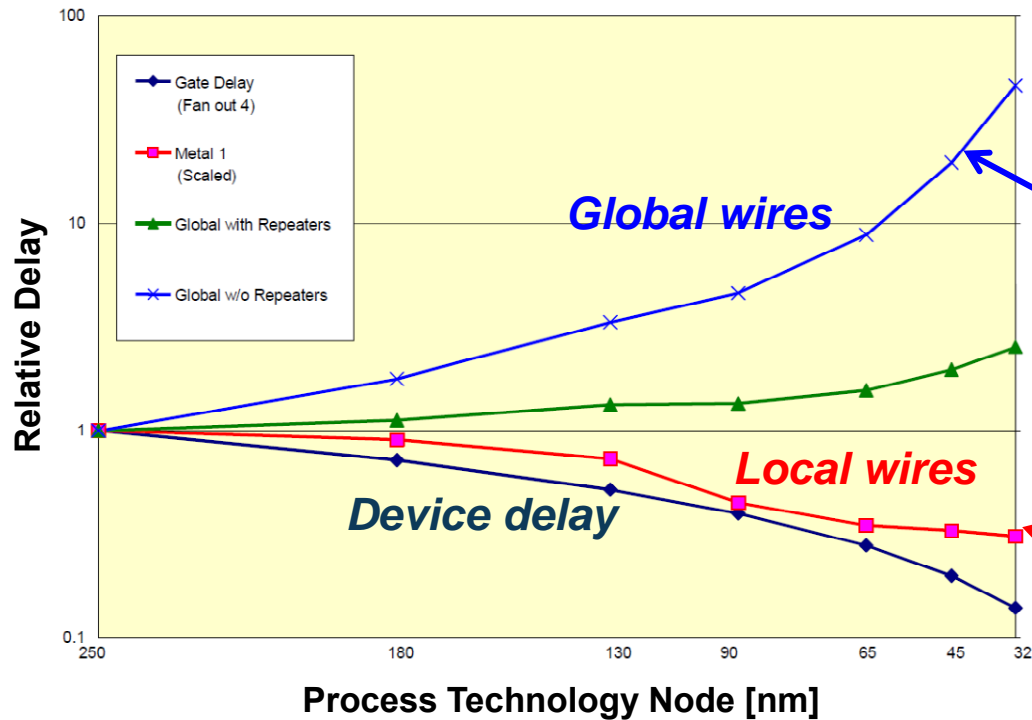


Number of terminals is limited by chip periphery !!

Interconnect Bottleneck

Ref. ITRS Interconnect Roadmap, 2003

Delays vs. feature size



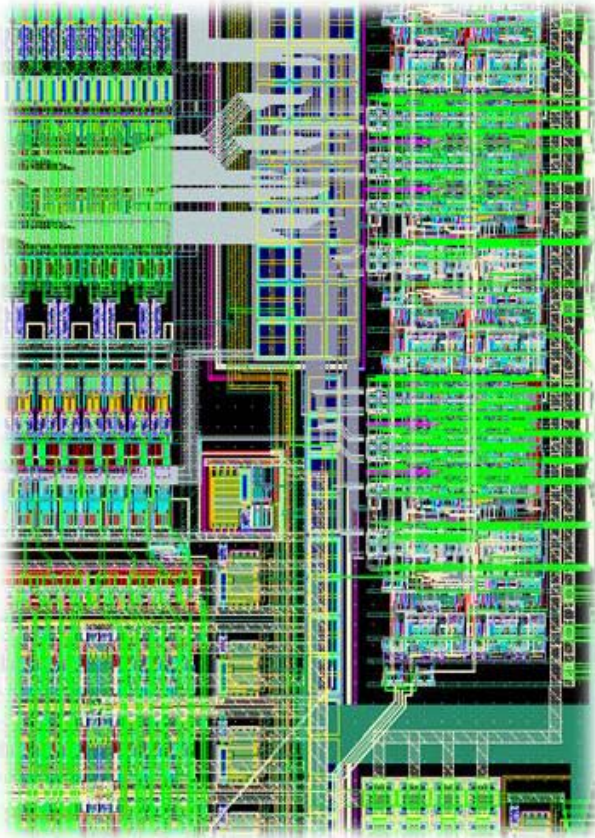
Cross-section of multi-level interconnection



Area and delay for interconnects grow much faster than active devices.

Complex Interconnects

Chip



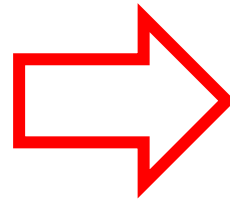
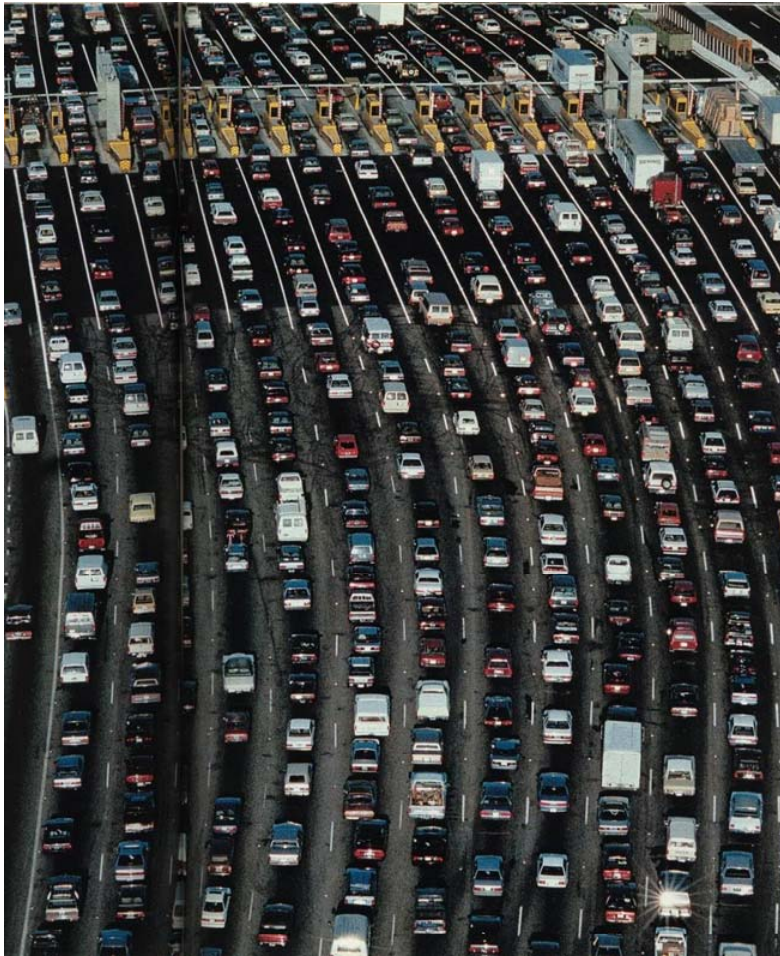
Board



Cables



Solutions for Traffic Jams

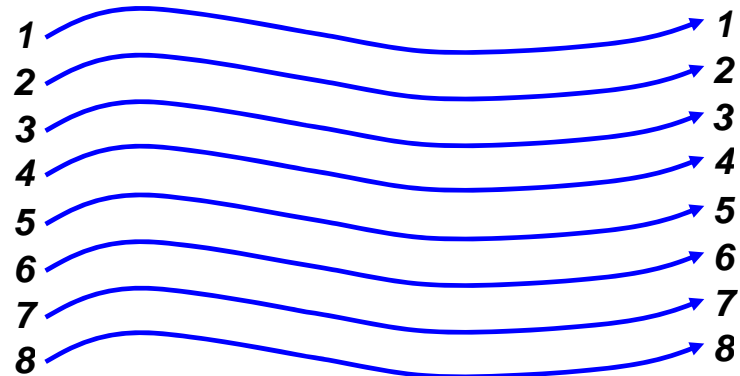


Serialization

Parallel Interconnect

: Multiple connection medium

Data transferred
concurrently !!

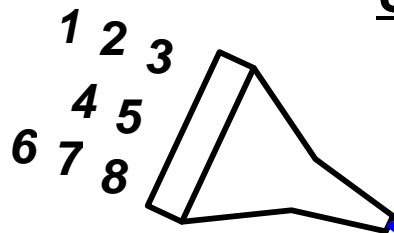


Data received
concurrently !!

Serial Interconnect

: Single connection medium

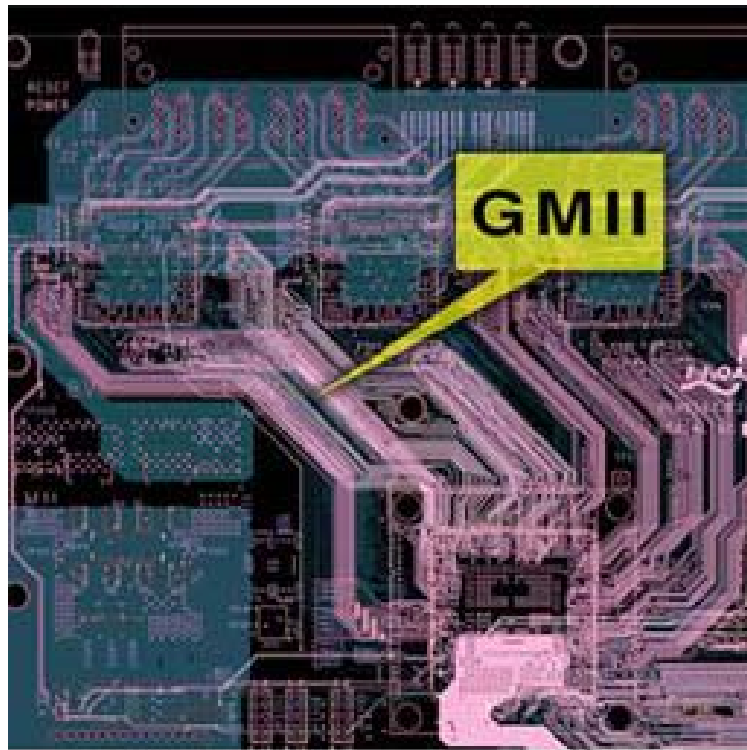
Data transferred
sequentially !!



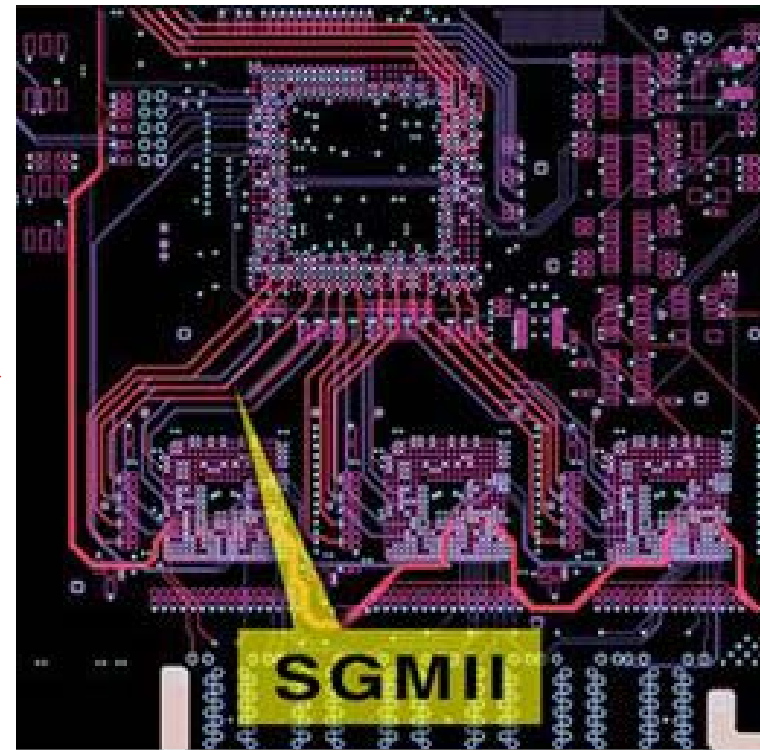
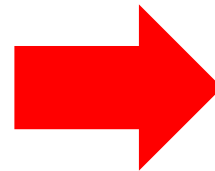
8..7..6..5..4..3..2..1

Data received
sequentially !!

Why Serial Interface ?

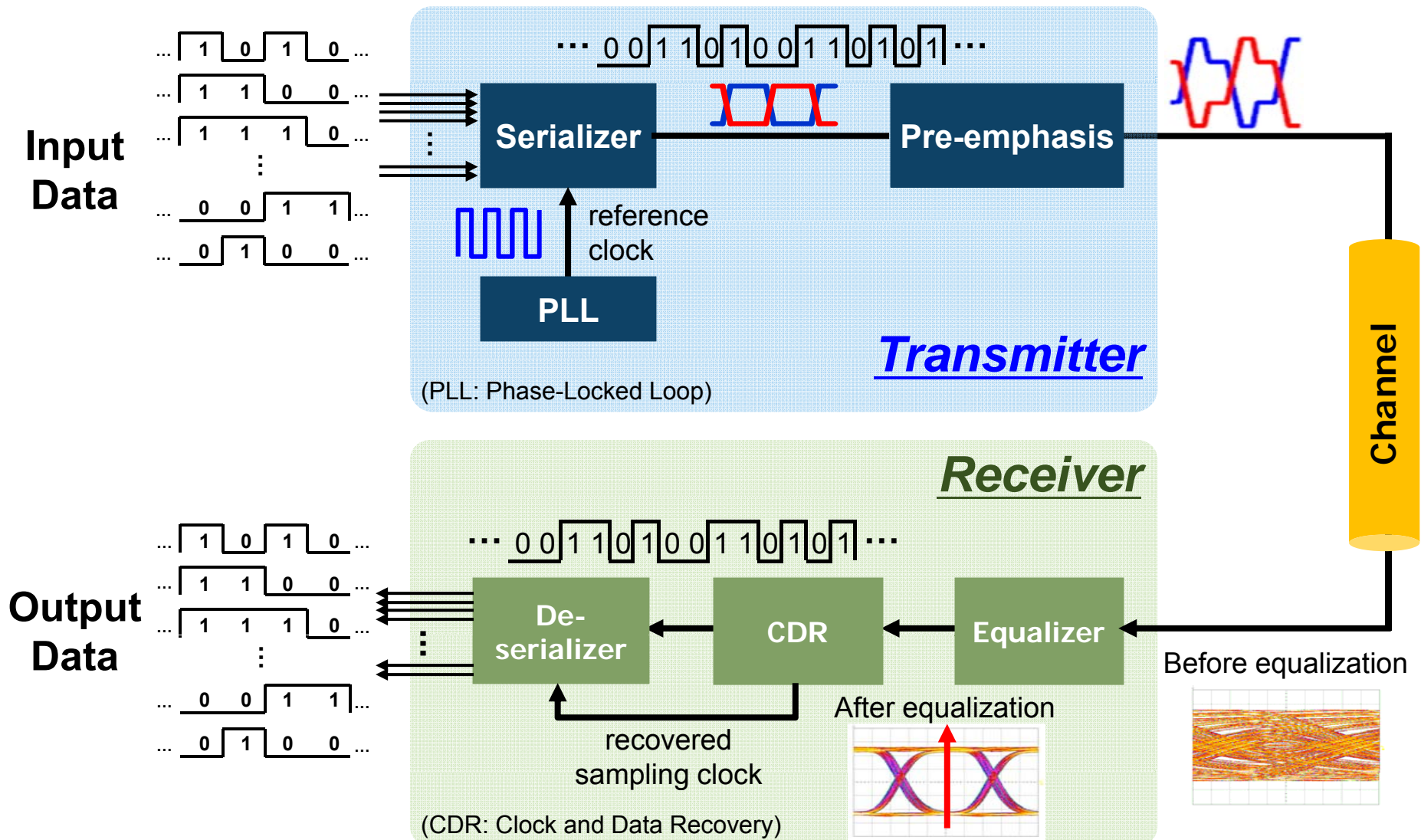


**Gigabit Media
Independent Interface (GMII)**
: Total 24 lines for 1 Gb/s



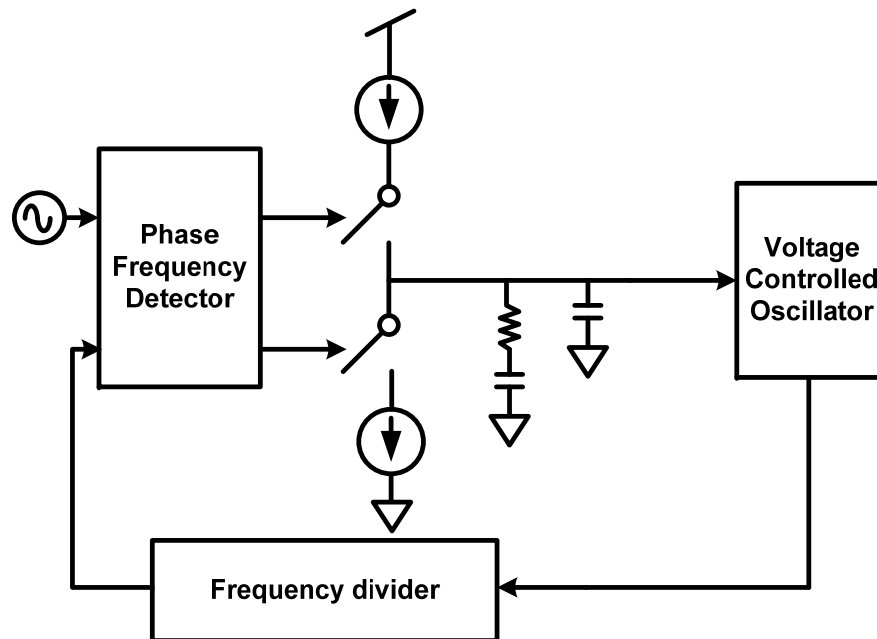
**Serial Gigabit Media
Independent Interface(SGMII)**
: Total 8 lines for 1.25 Gb/s

High-Speed Serial Link

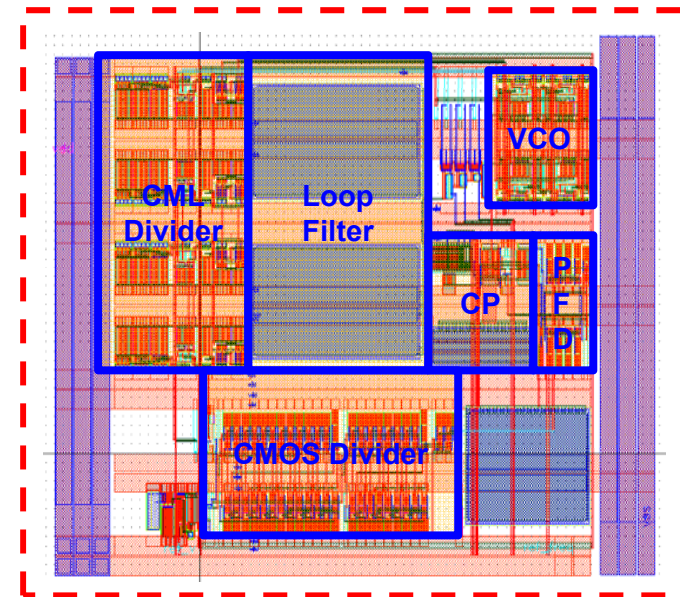


Phase-Locked Loop (PLL)

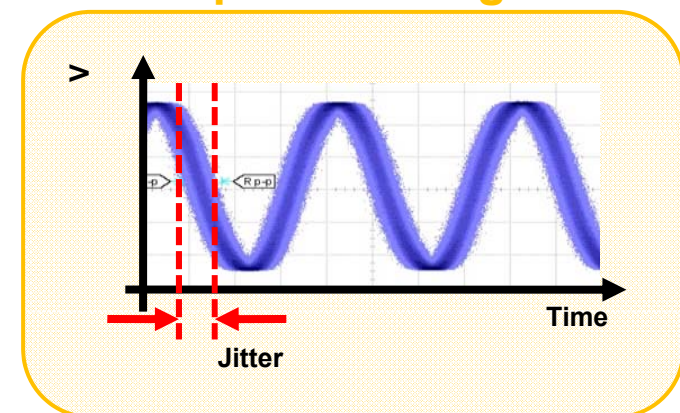
- Provide clean digital clock signal



- Compare the output phase with the input phase
- Charge-pump PLL
- Specification : locking time, clock jitter

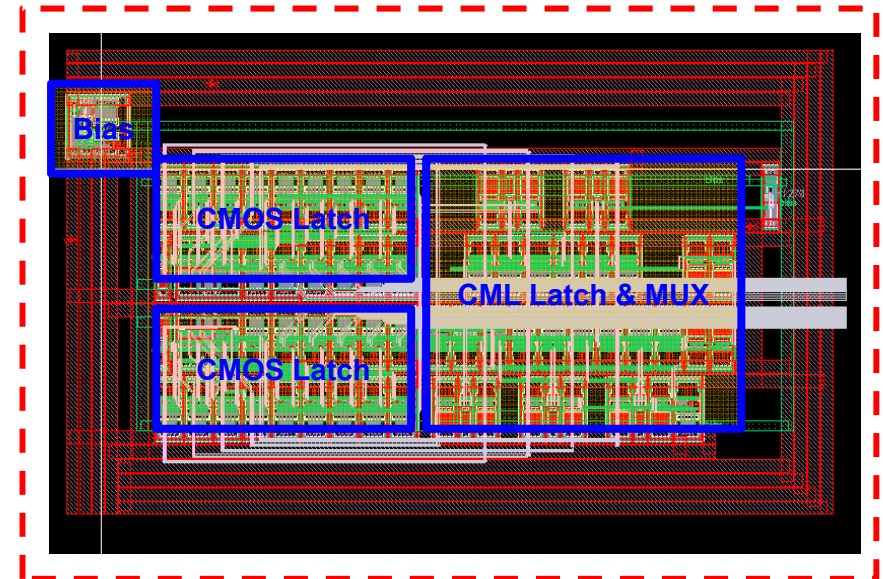
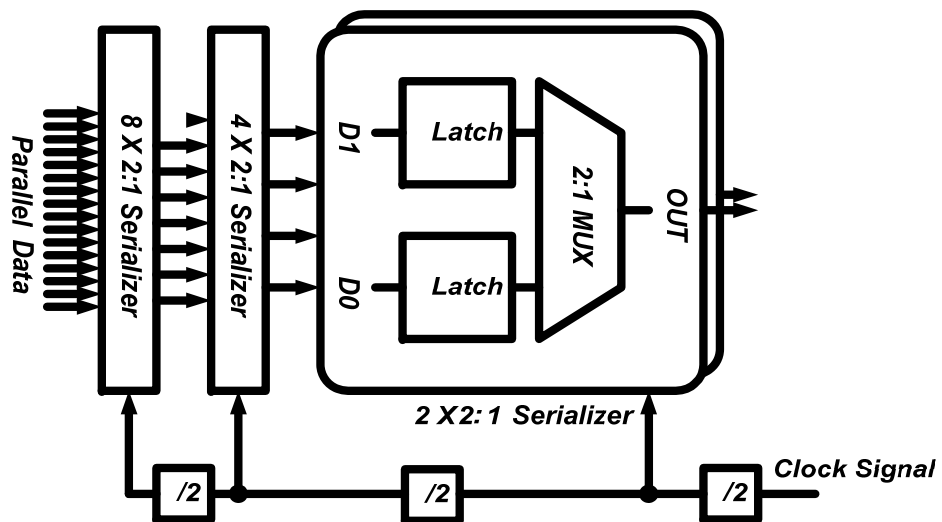


Output clock signal



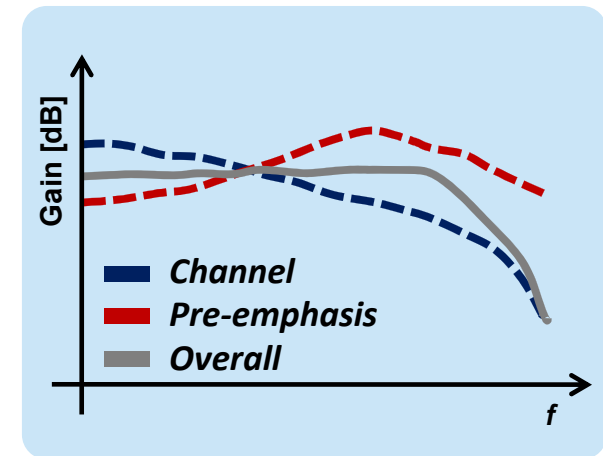
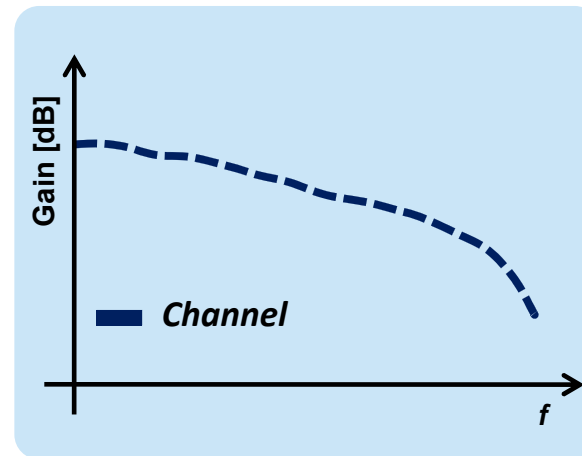
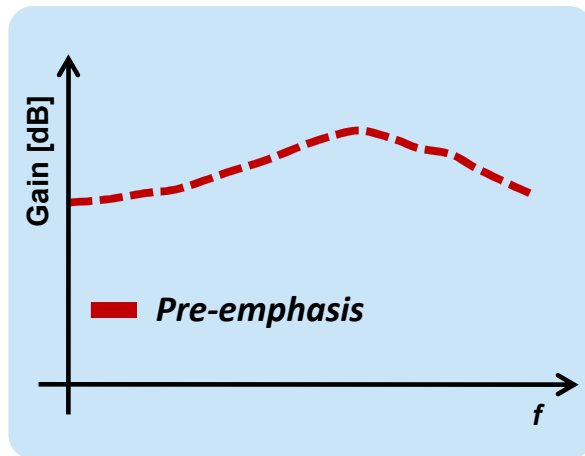
Serializer

- Parallel data conversion into serial data

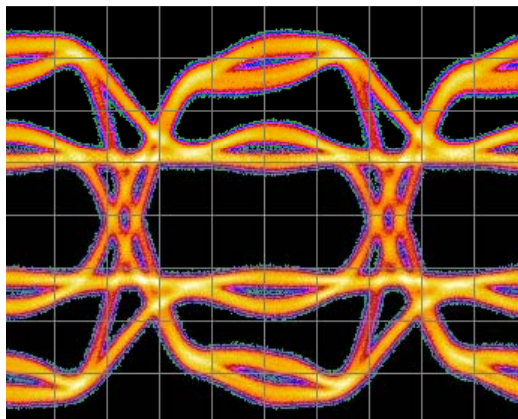


Pre-Emphasis

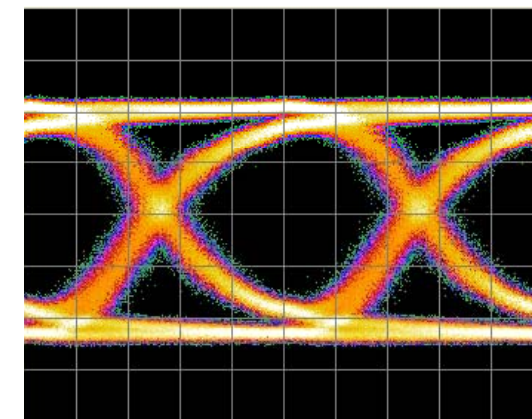
- Transmitter: pre-emphasis



Pre-emphasis output

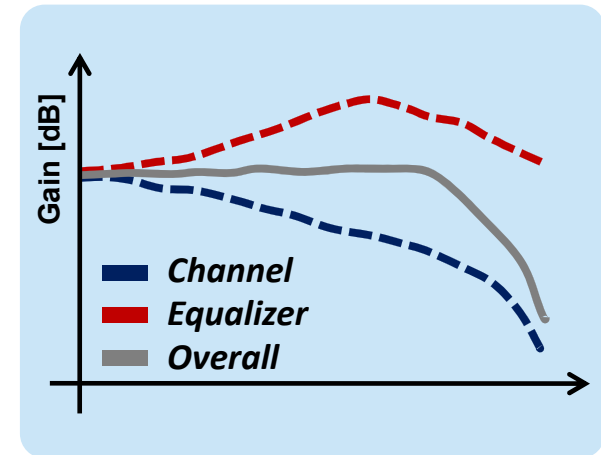
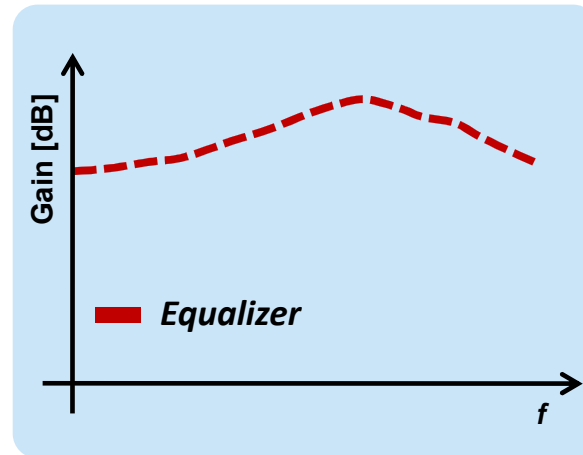
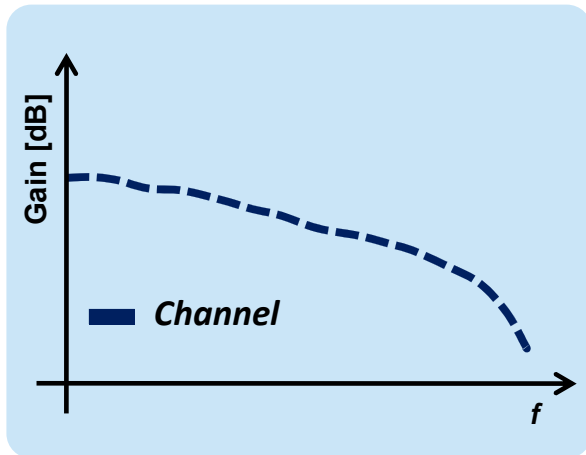


Channel output

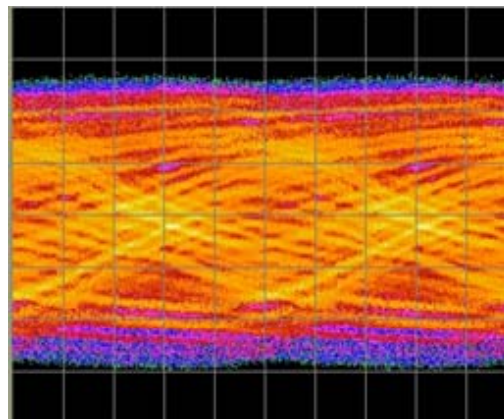


Equalizer

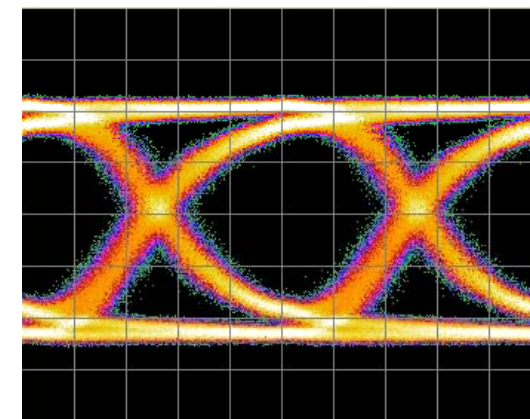
- Receiver: equalizer



Channel output

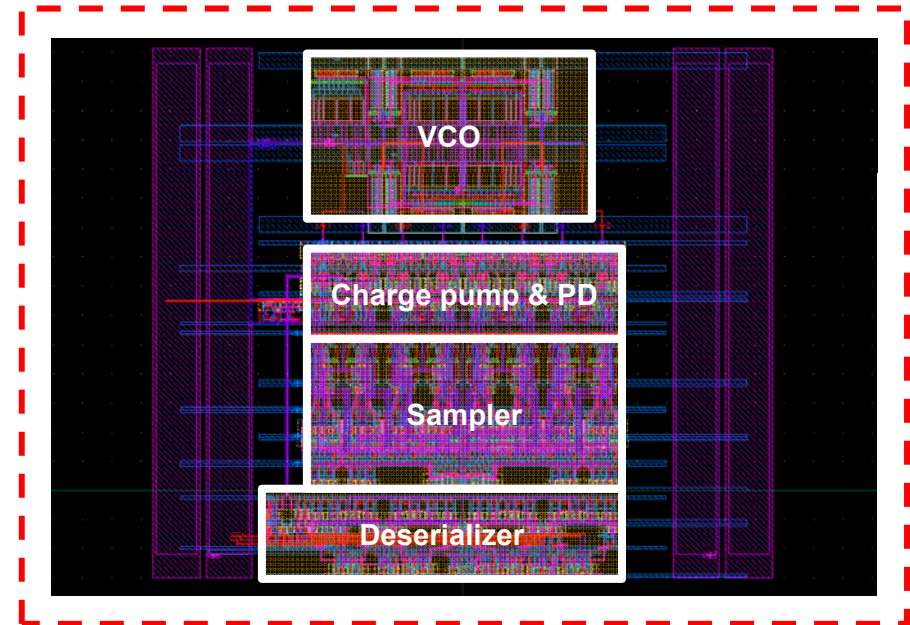
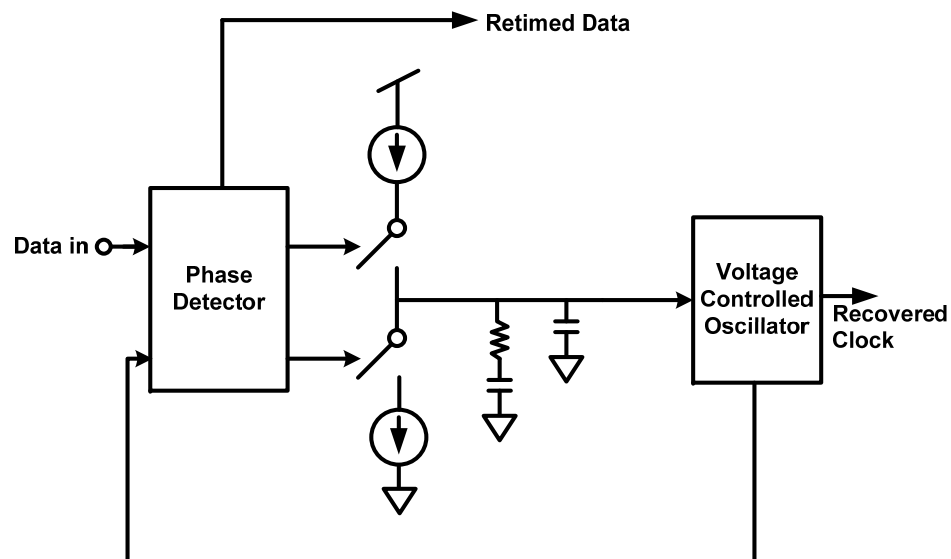


Equalizer output



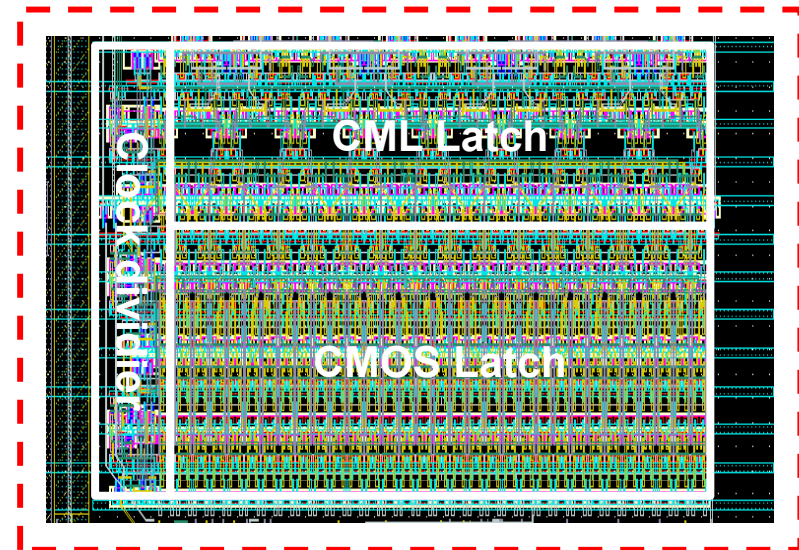
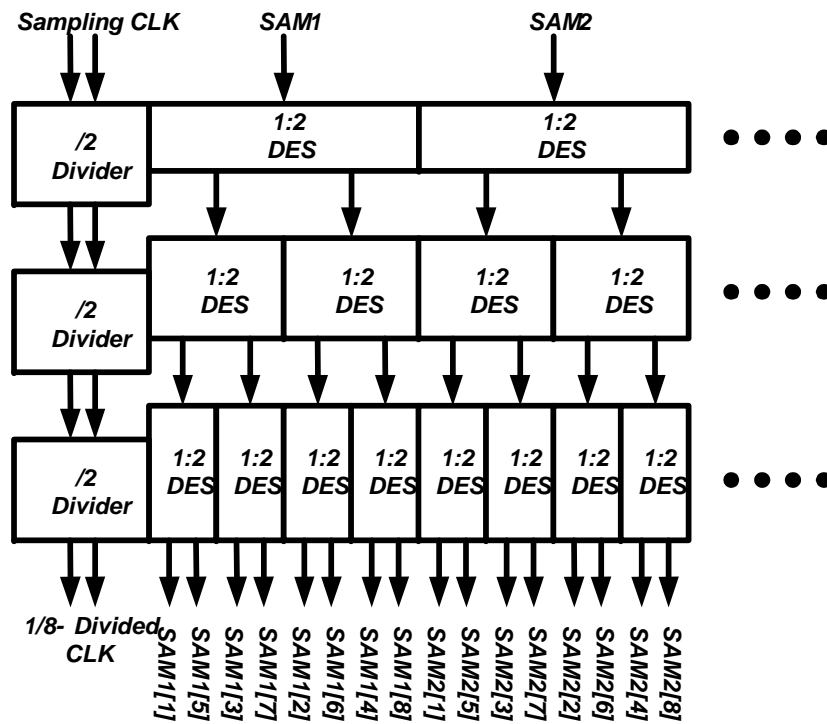
Clock and Data Recovery (CDR)

- Recover clock signal from input data and generate retimed data

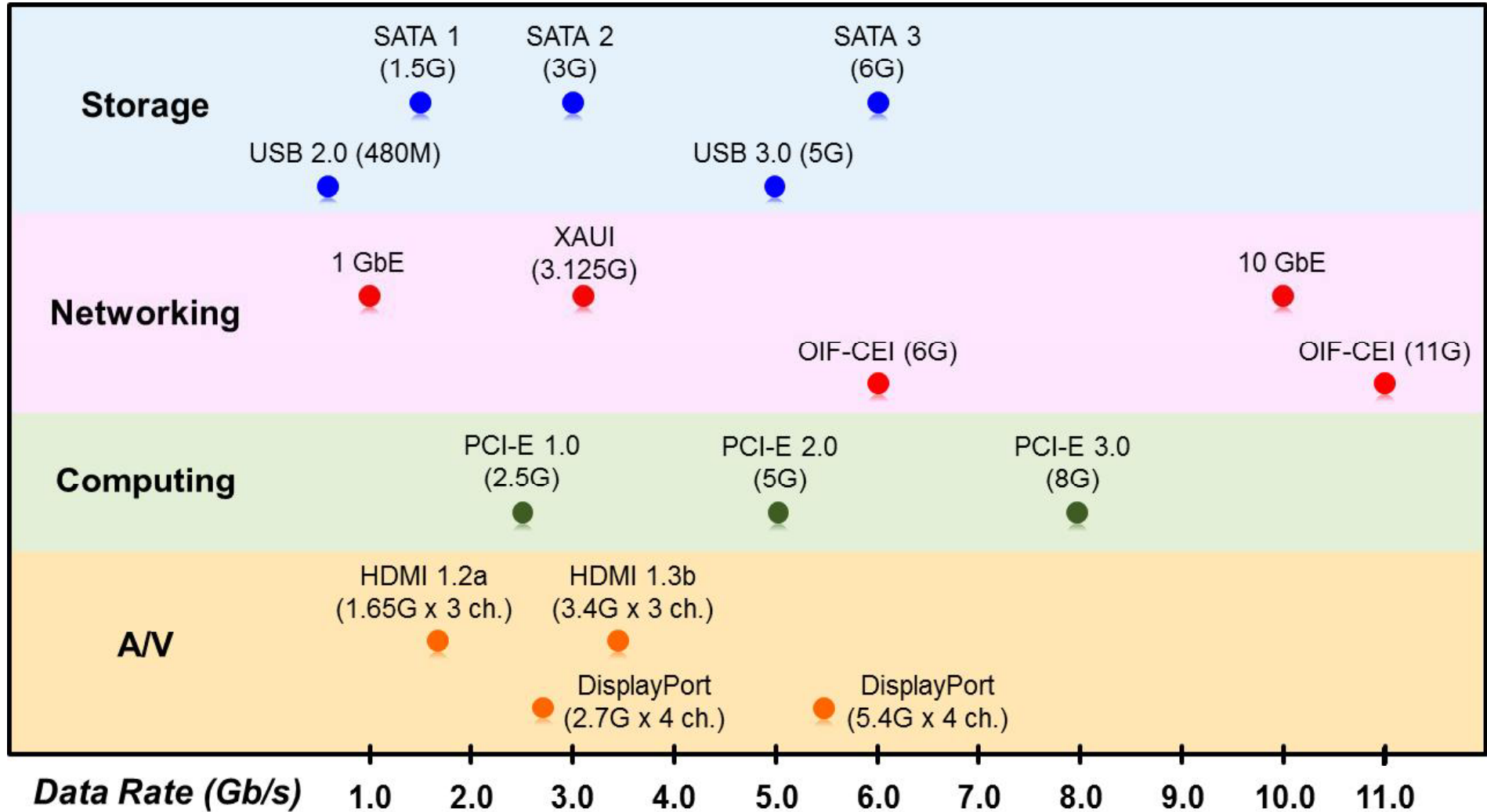


Deserializer

- Serial data convert into parallel data



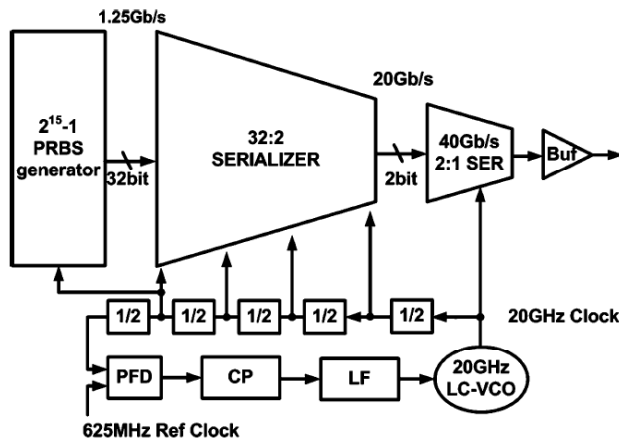
Technology Directions



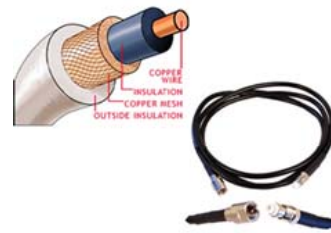
40-Gb/s Serial Link Transceiver

Ref. J. K. Kim, JSSC, May 2009

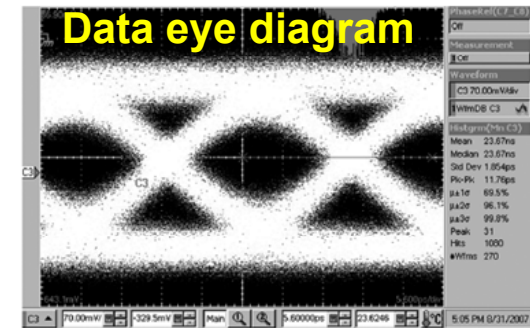
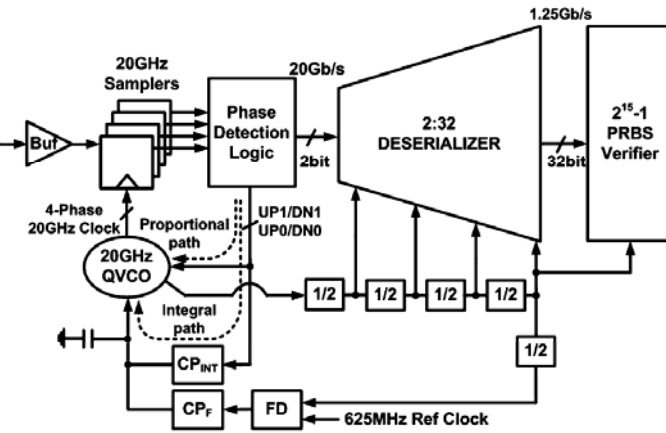
40-Gb/s serializing transmitter



1m coaxial cable



40-Gb/s deserializing receiver



- 0.13- μm CMOS technology
- Inductive peaking equalizer, phase detector, clock buffer, and sampler
- Quadrature LC VCO with bang-bang control
- Chip area & power consumption Tx: 1.7 x 2.2 mm² / 1.56 W (1.45 V)
Rx: 1.7 x 2.9 mm² / 2.04 W (1.45 V)

Frequency-Dependence Loss

Typical cables



RG-174
(Thin, flexible)

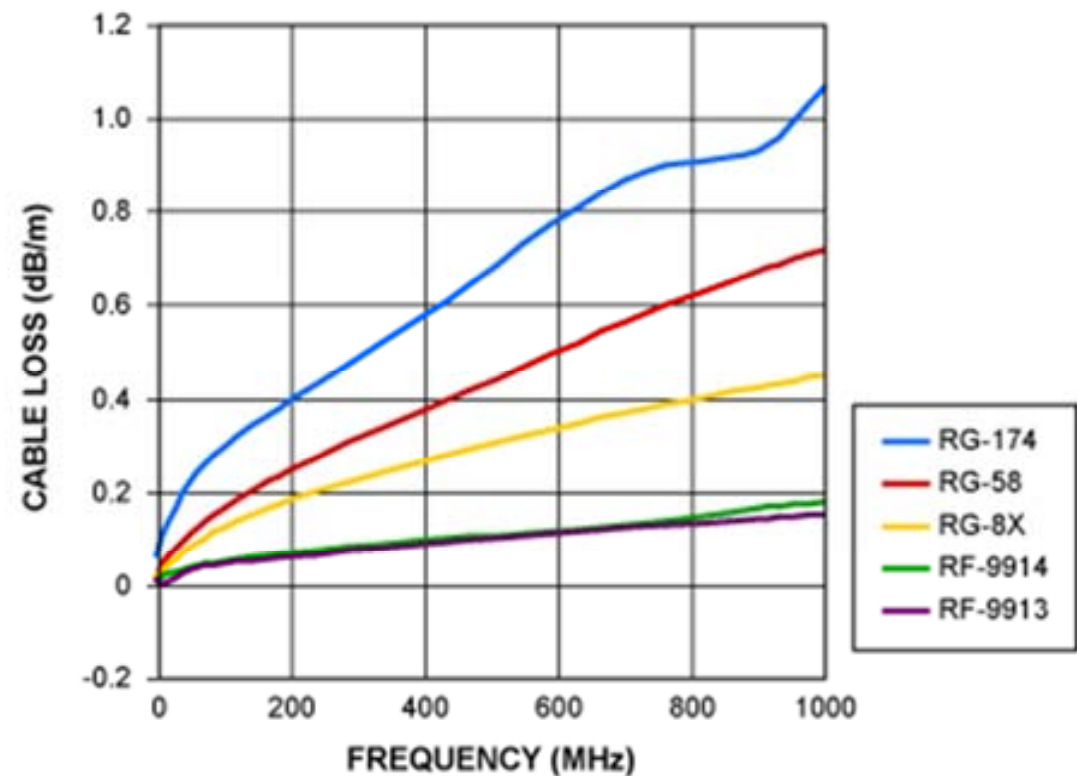


RG-8X
(Most popular)



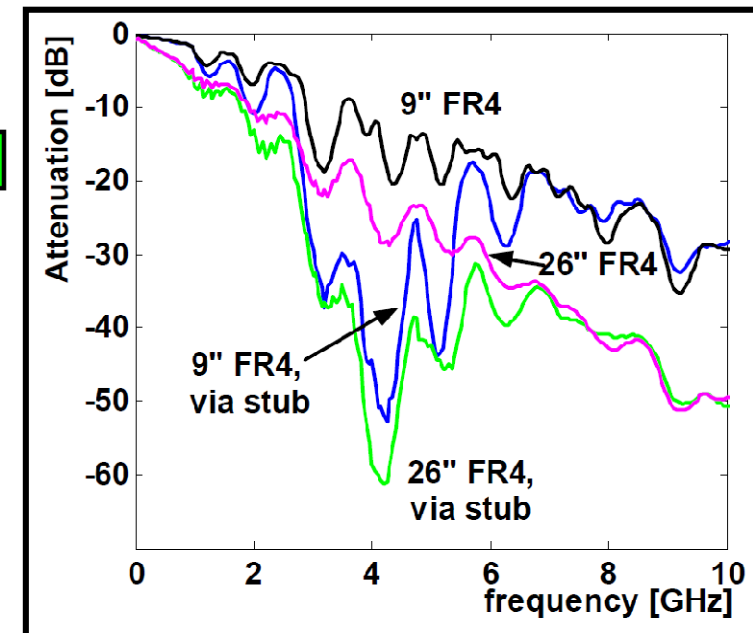
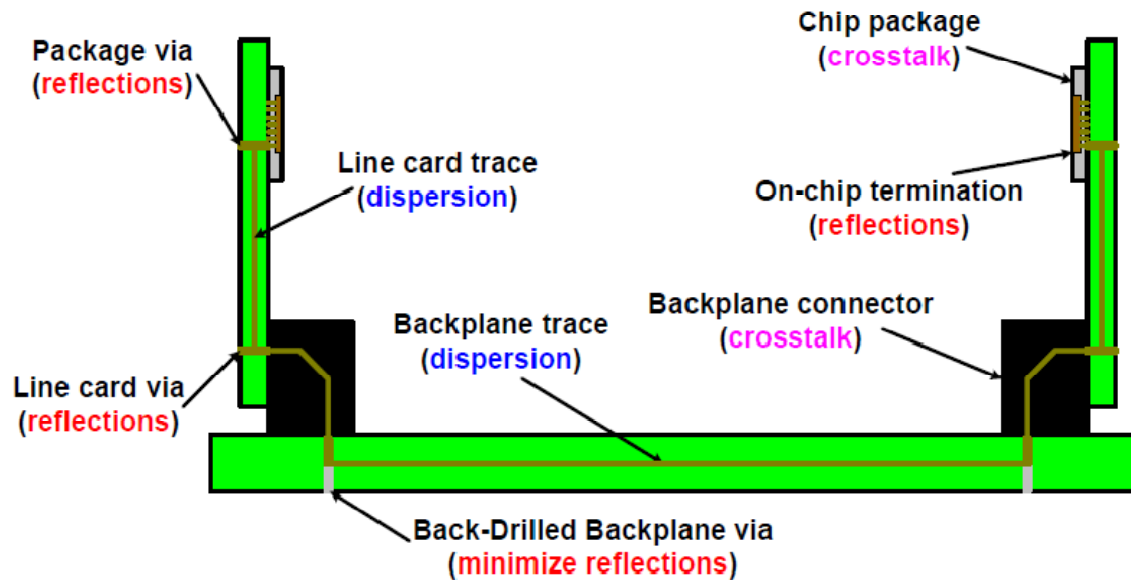
RF-9913
(VHF/UHF application)

Cable losses for typical cable



Frequency-Dependence Loss

• Backplane interconnection



Better Channel ?

Transmitter

- Serializer
- Phase-Locked Loop (PLL)
- Pre-emphasis

Electrical-to-
optical (E/O)
conversion

...1010110011...



Receiver

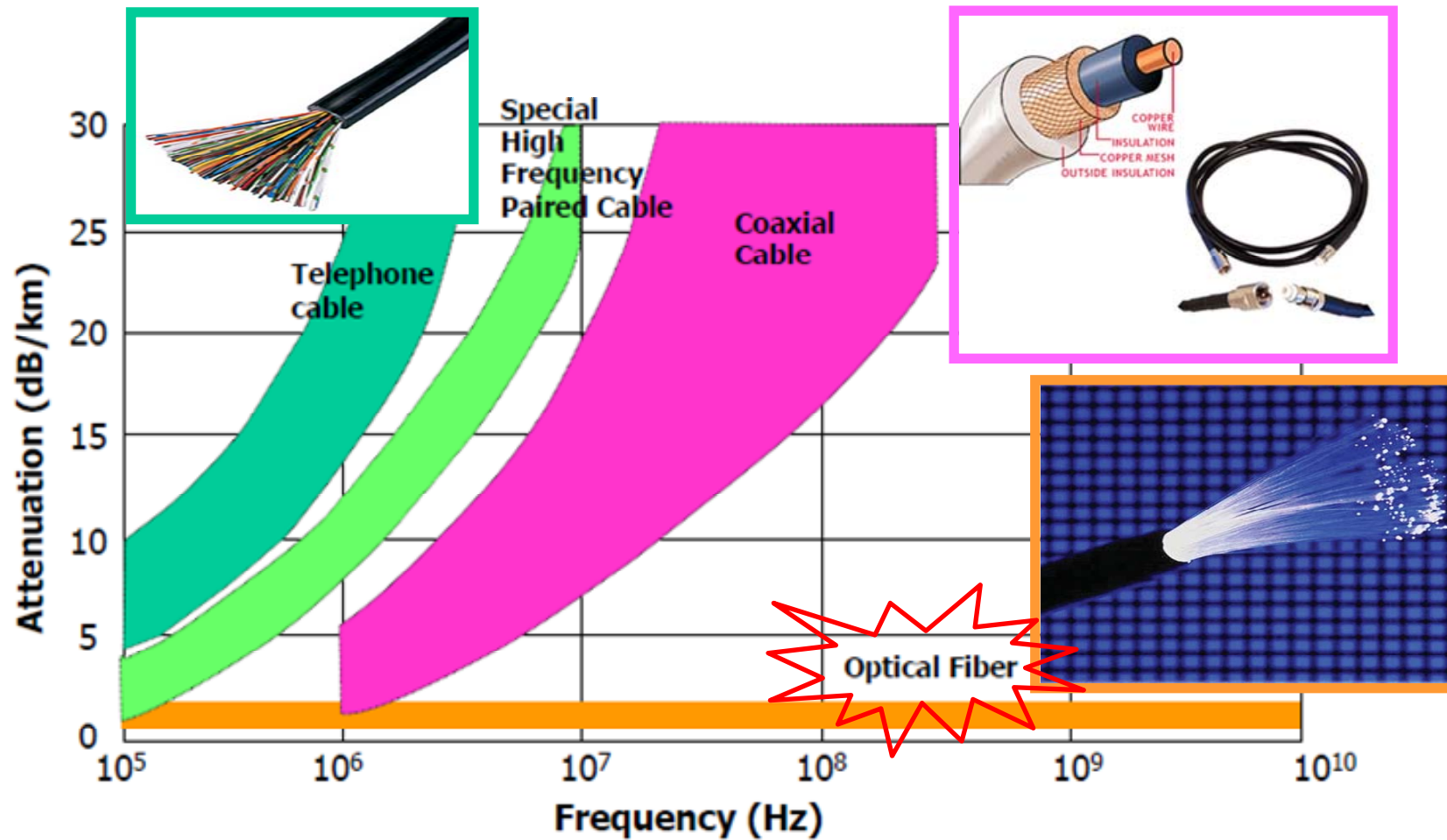
- Equalizer
- Clock & Data Recovery (CDR)
- Deserializer

Optical-to-
electrical (O/E)
conversion

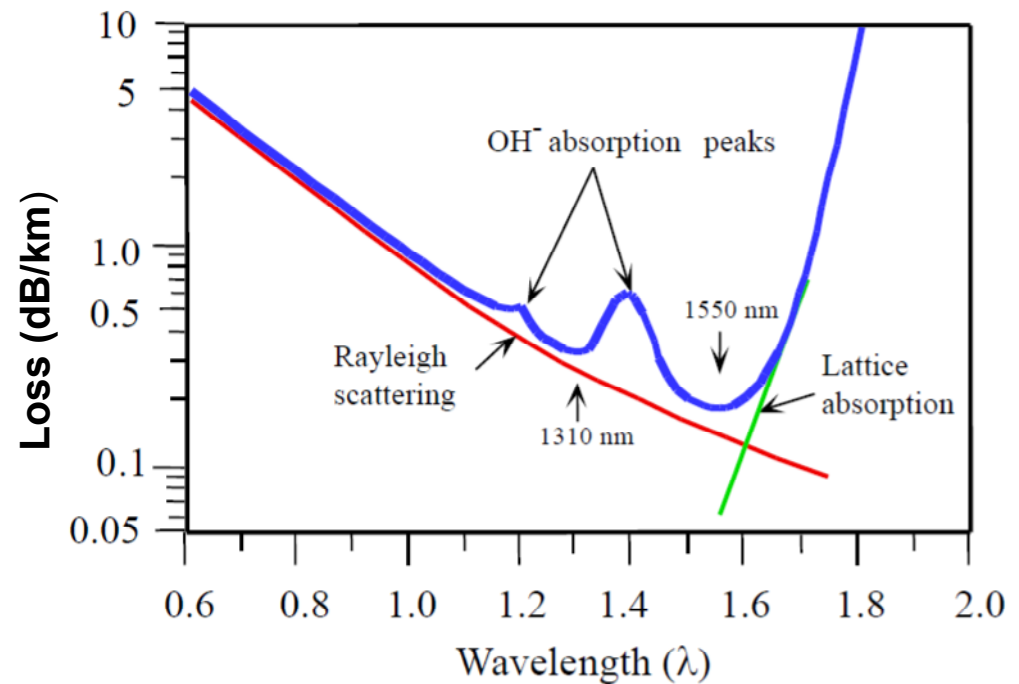
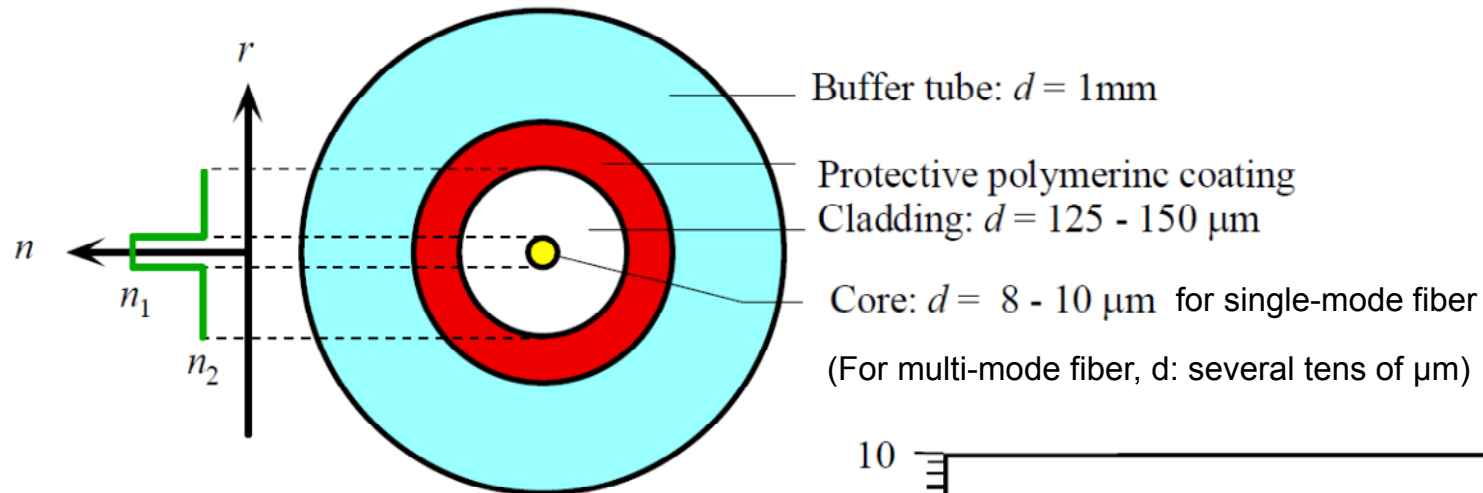
...1010110011...

Use light over fiber !!

Loss of the Communication Cables



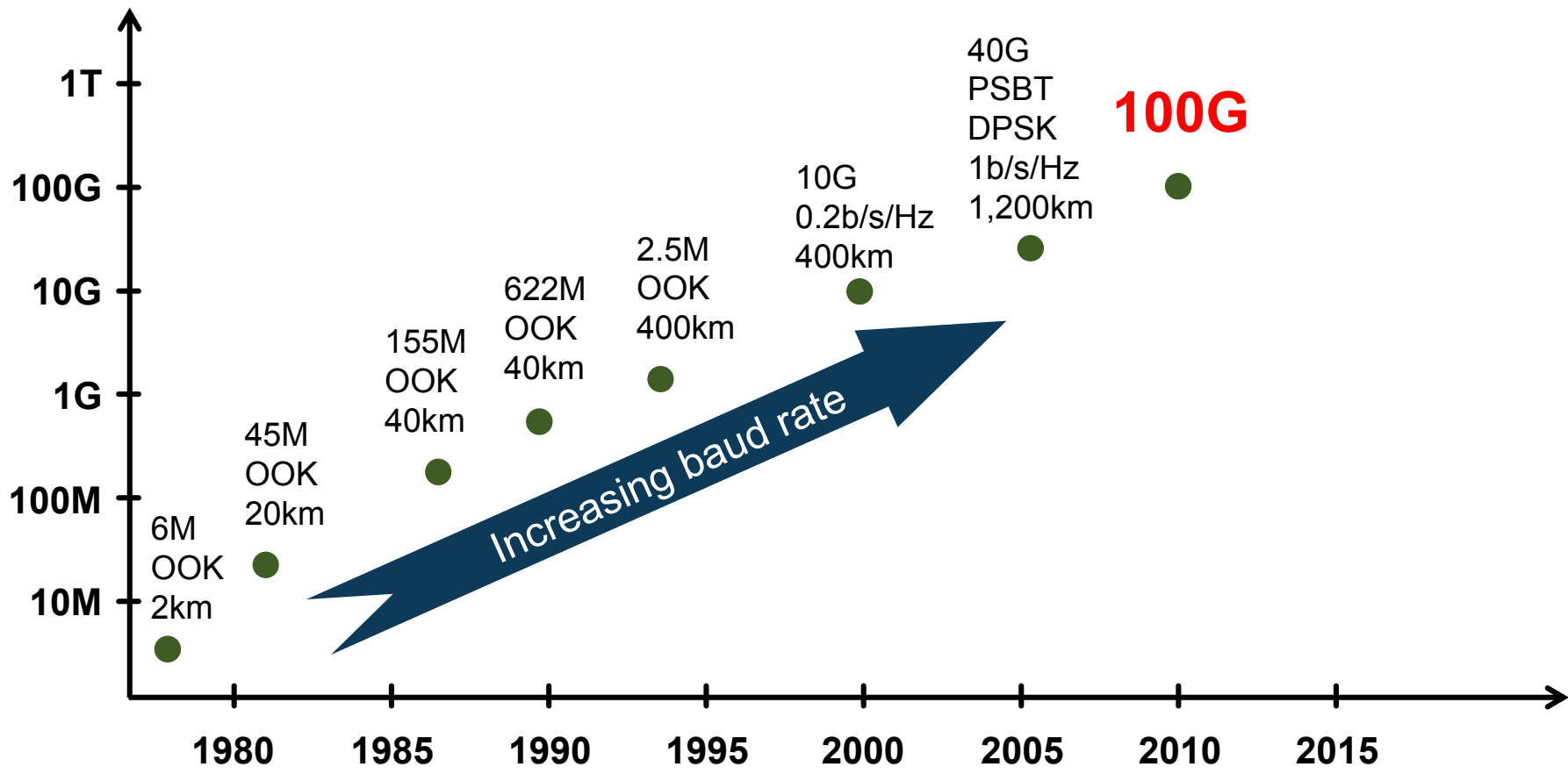
Optical Fiber



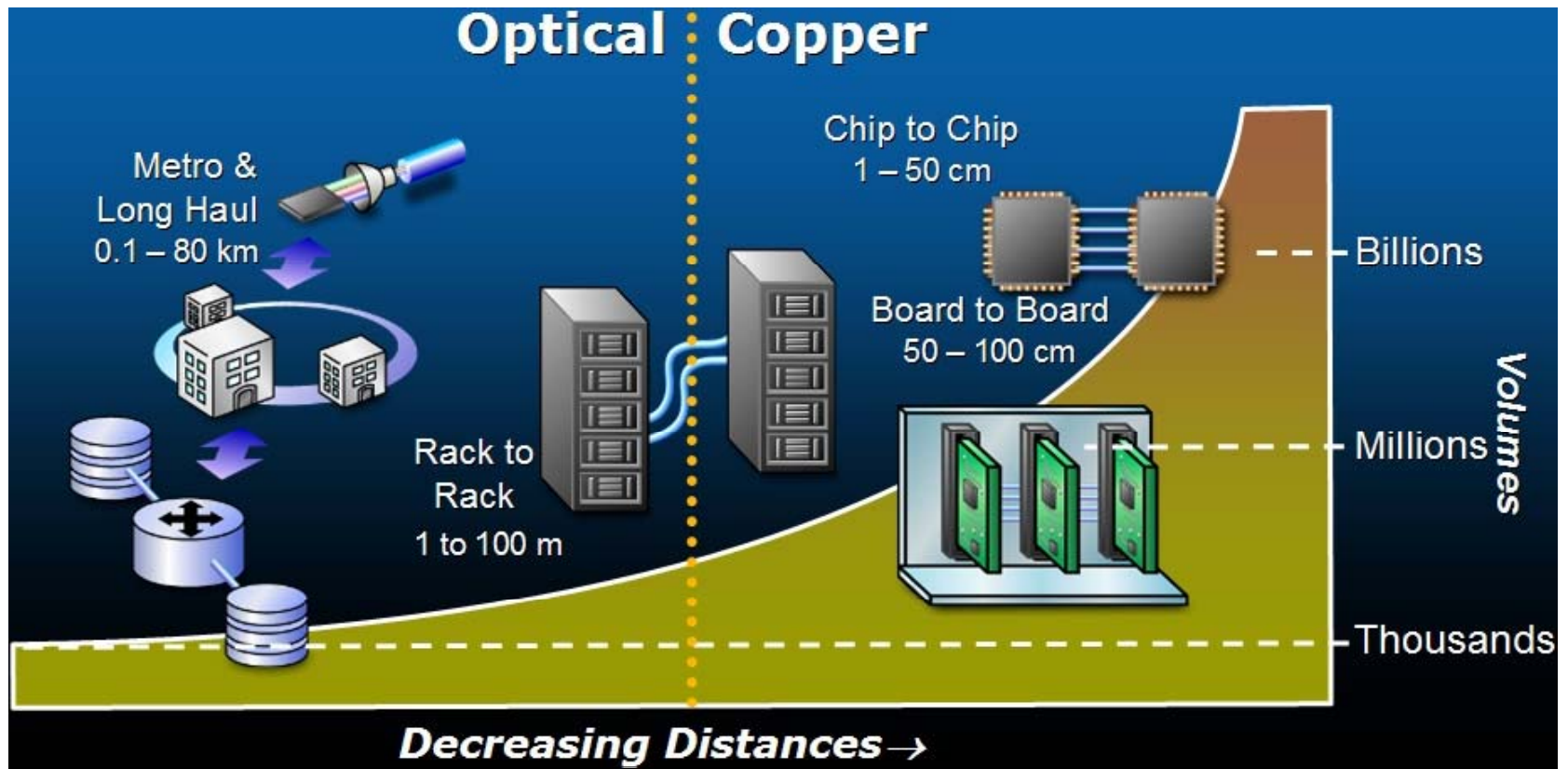
Long-Distance Optical Communication

Ref. J. R. Saunders, "100G Cost/Performance Optimization," ECOC, Sep. 2009

Low loss silica MMF fibers GaAs lasers Single mode fiber InGaAsP lasers EDFA WDM Hard FEC External modulation Advanced modulation schemes



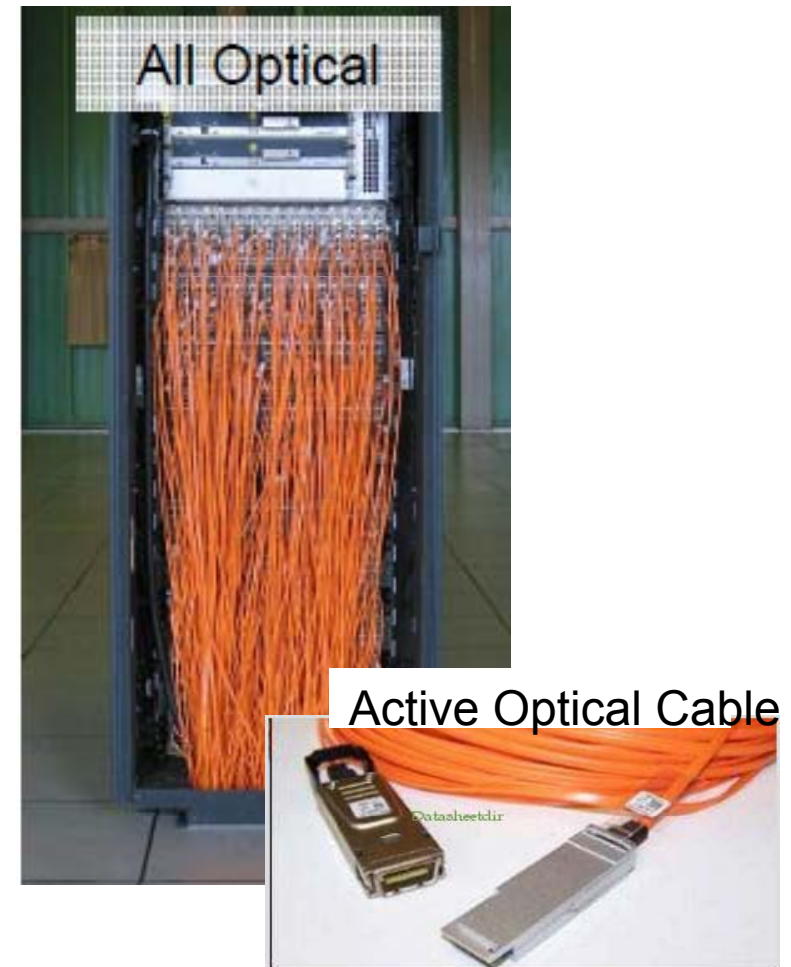
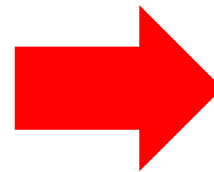
Boundary is Moving !!



(From <http://engineering.ucsb.edu/bowers/presentation.php>)

- Long distance: Optical communication
- Short distance: Electrical interconnect

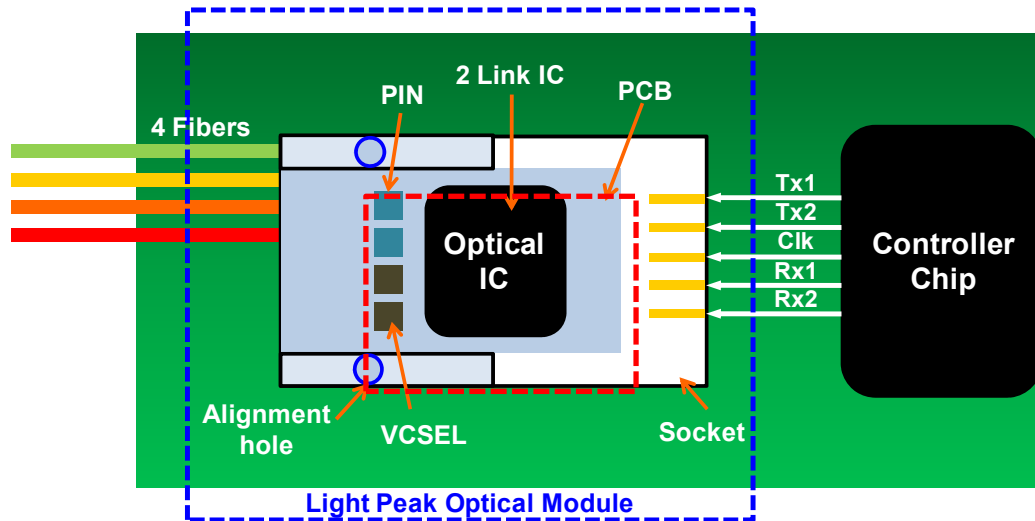
Rack-to-Rack Interconnects



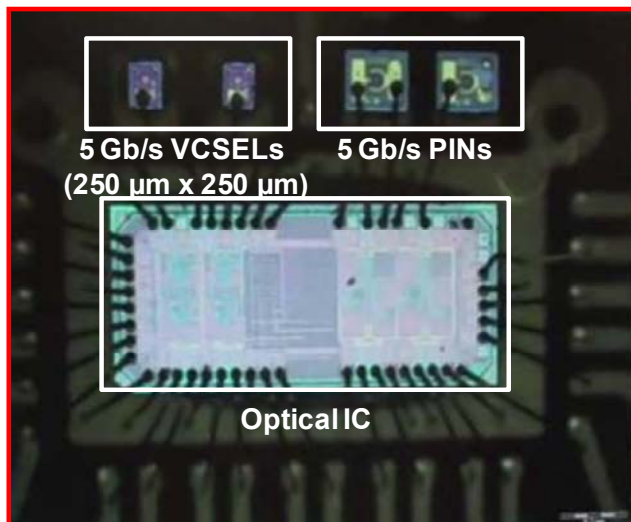
- Bulk
- Bend and weight problem

- Thin and light
- Very organized

Intel's Light Peak



*Light Peak Optical Module
(12 mm x 11 mm)*



- 10-Gb/s dual channels transceiver
: fabricated with 65-nm CMOS technology
- 850-nm VCSEL-based optical interconnect (*Oclaro*)
- The driver and receiver silicon (*IPtronics*)

Intel's Light Peak

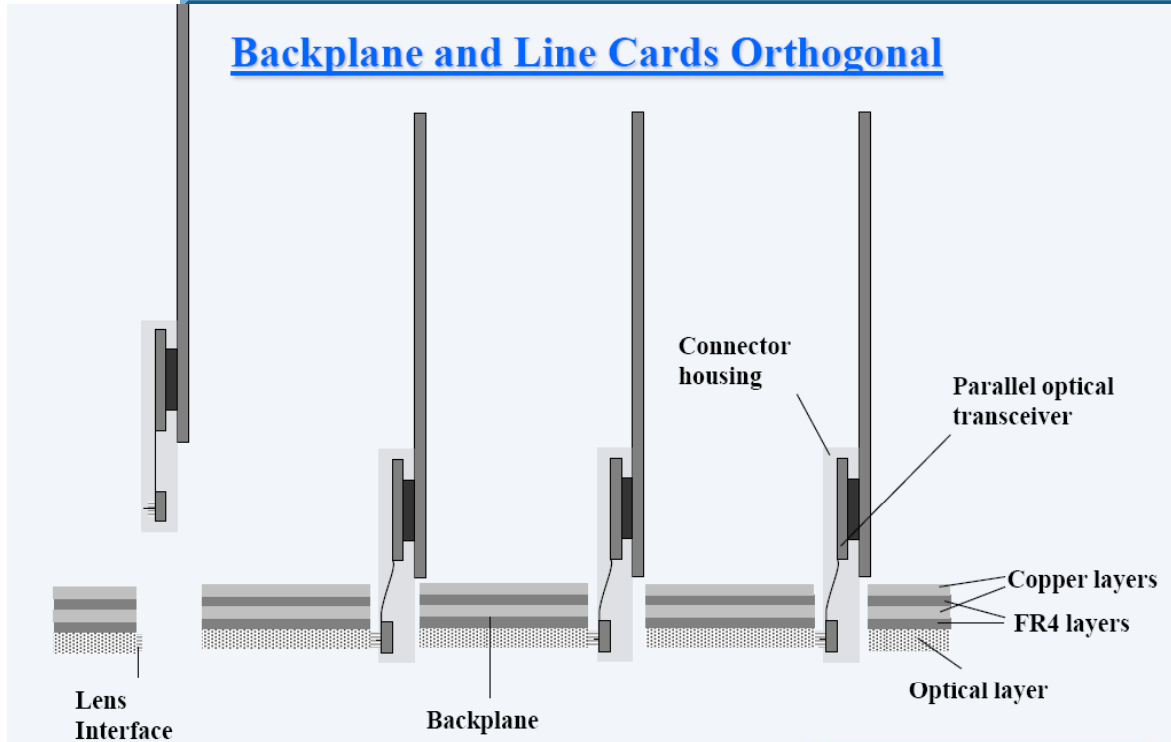
- **Future client usage models**



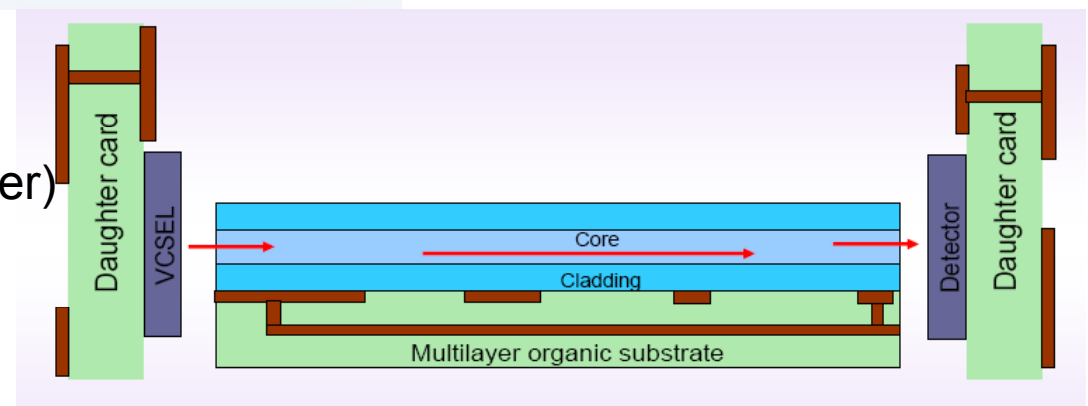
- **Fast external storage**
 - SSD or HDD arrays transferring at 10Gb/s and faster.
 - At 10Gb/s, you can transfer a full-length Blu-Ray movie in less than 30 seconds.
- **Advanced docking**
 - High-performance docks, display docks, media docks, etc
- **PC-to-PC high-speed connection**
 - Transfer files, PC migration, etc
- **Simplified home connectivity**

Optical PCB

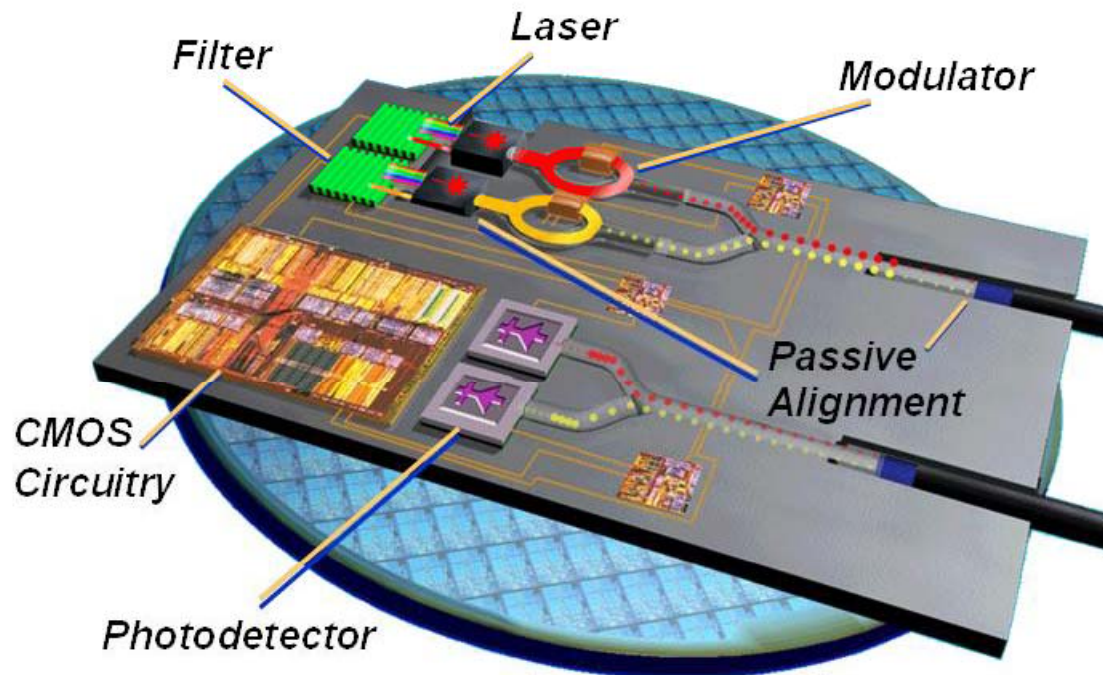
Backplane and Line Cards Orthogonal



- 850-nm VCSEL (Vertical Cavity Surface Emitting Laser)
- Polymer waveguides
- Advanced packaging technology



Chip-to-Chip Interconnect: *Silicon Photonics*



Ref. Intel Corporation, 2006

***Fully integration of the all optical components
on a single chip with silicon technology.***

Reading Assignment

R. Soref, "The Past, Present, and Future of Silicon photonics,"
IEEE Journal of Selected Topics in Quantum Electronics, Vol. 12., No. 6,
p.1678, 2006.