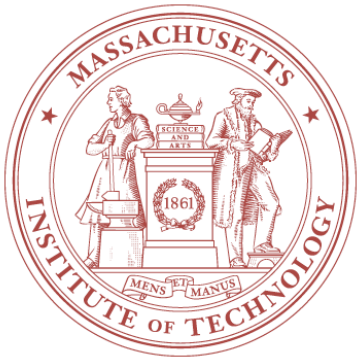
Future State-of-the-Art Electrical Interconnect

Byungsub Kim* and Vladimir Stojanović

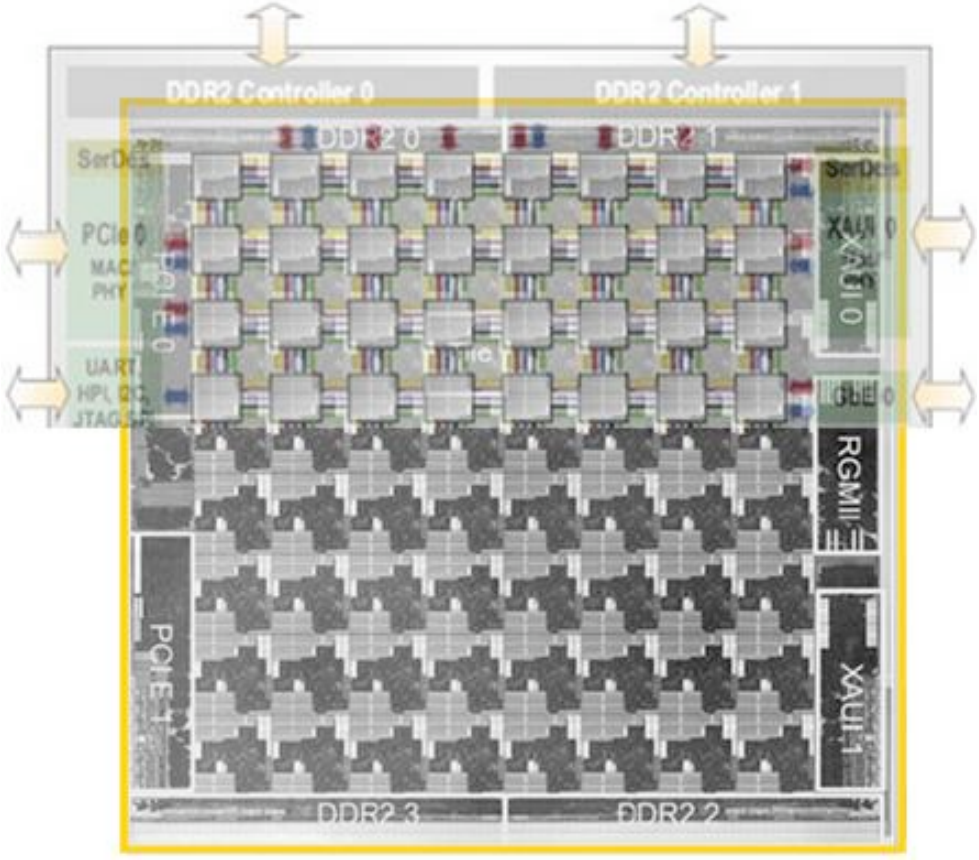


Integrated Systems Group

Massachusetts Institute of Technology

*Currently with Intel Corporation

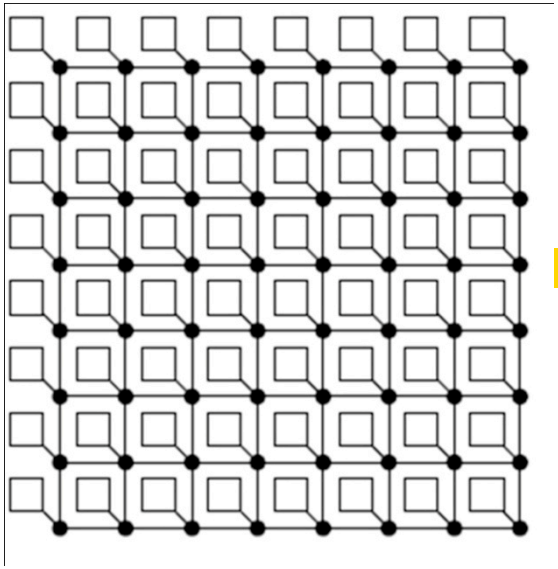
Many-core processor era



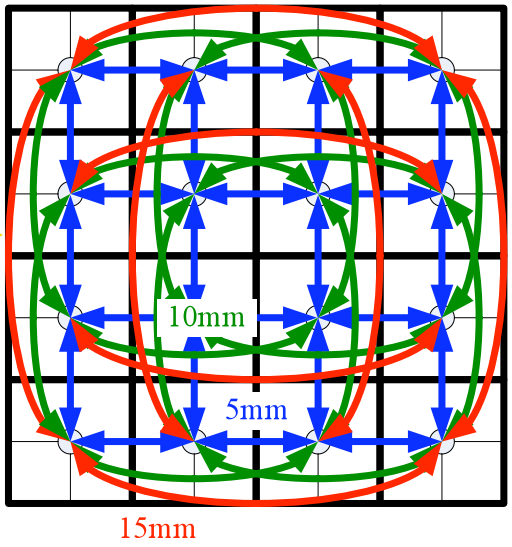
Tilera 64 core processor

➔ 1000 cores in the future ?

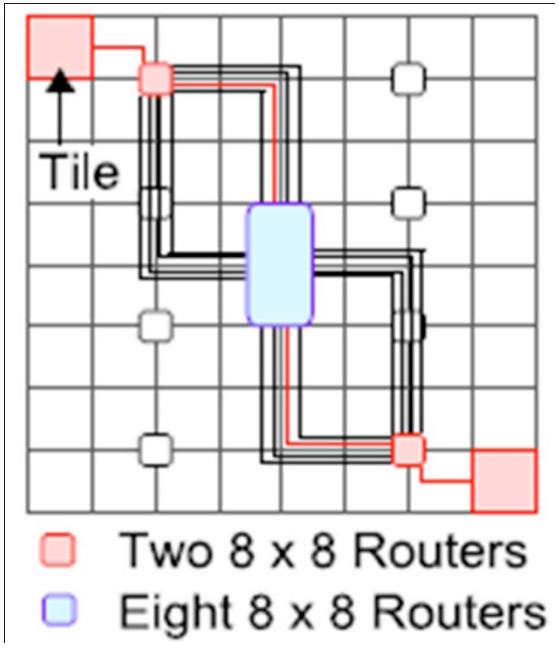
Global interconnects for latency



Mesh



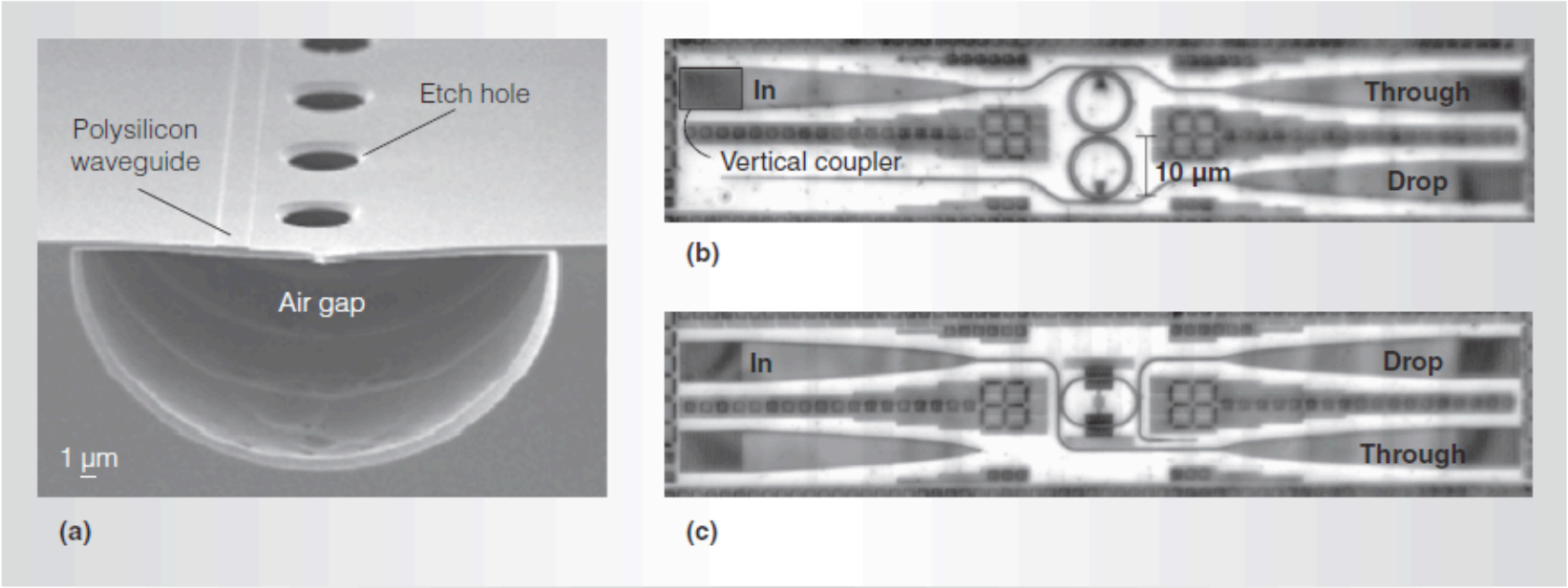
Flattened Butterfly



Clos

- Increasing number of cores ➔ latency issue.
- Global NoC interconnects are attractive.

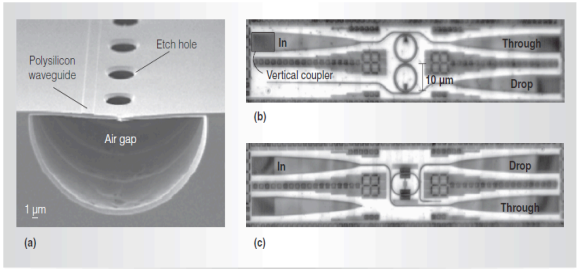
Nanophotonic on-chip interconnect



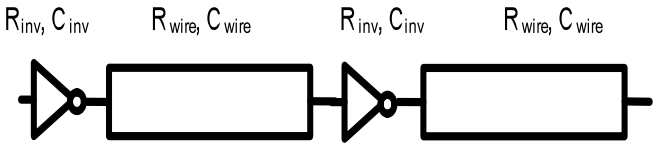
Batten et. al., Micro2009

- Large bandwidth with small energy cost per bit over long distance
- Extra cost
  - CMOS compatible fabrication, extra area, energy overhead.
- We are keep improving …

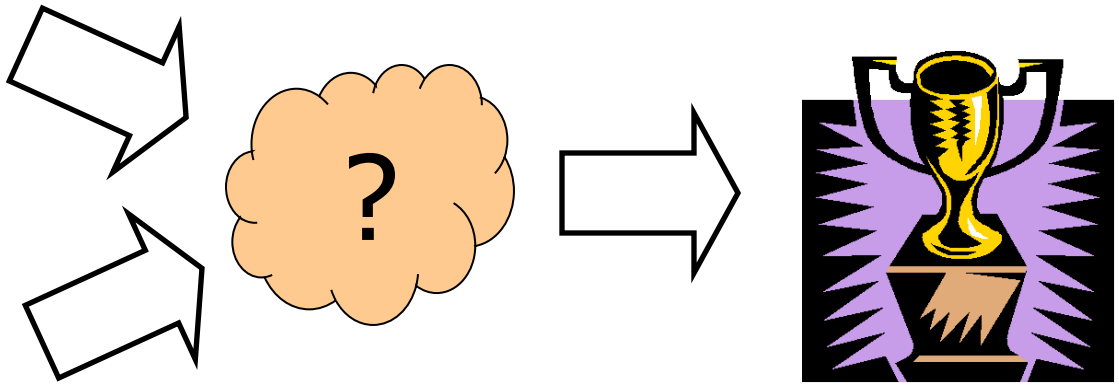
The winning interconnects?



nanophotonics

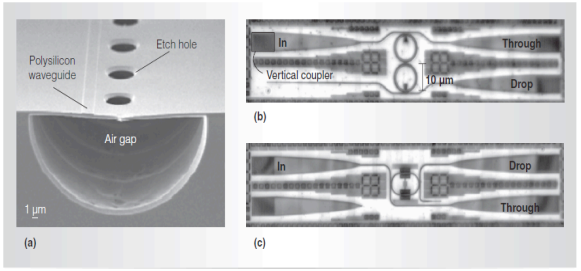


electrical repeater

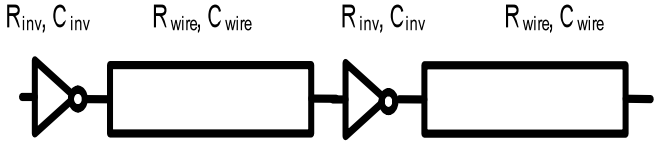


- Nanophotonics v.s. electrical repeater
- Compare bandwidth and power consumption.

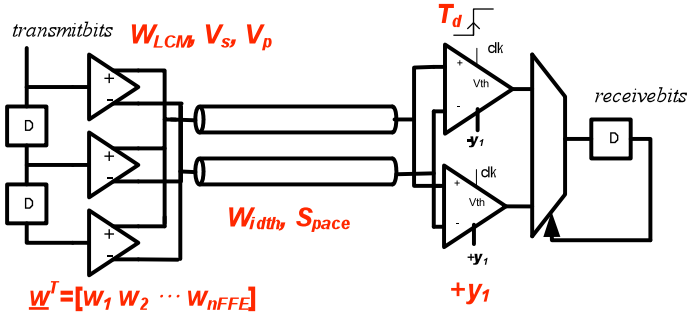
The winning interconnects?



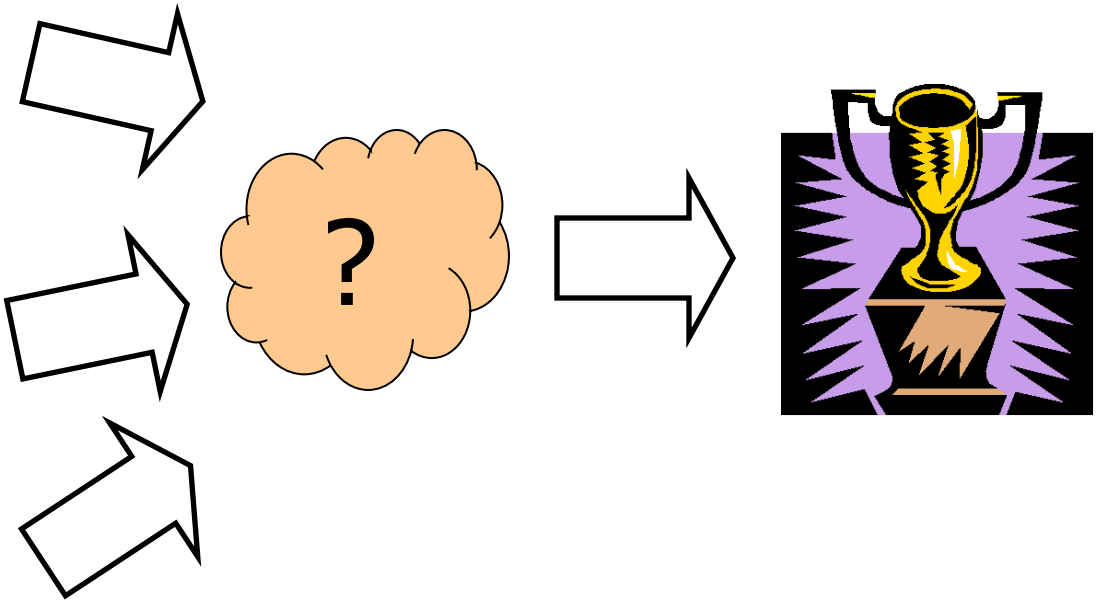
nanophotonics



electrical repeater



electrical equalizer



- Equalized interconnects.
- Consideration on area and latency.

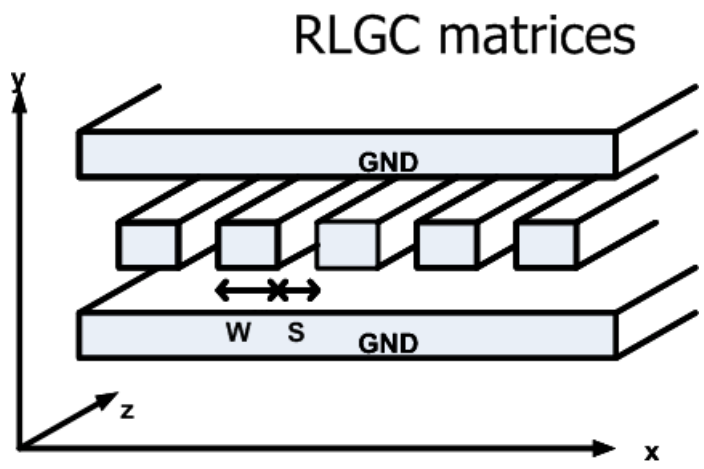
Outline

- Fair comparison metrics.
- Trade-off of repeated interconnects.
- Trade-off of equalized interconnects.
- Status of equalized electrical interconnects based on silicon measurement.

Fair interconnect metrics?

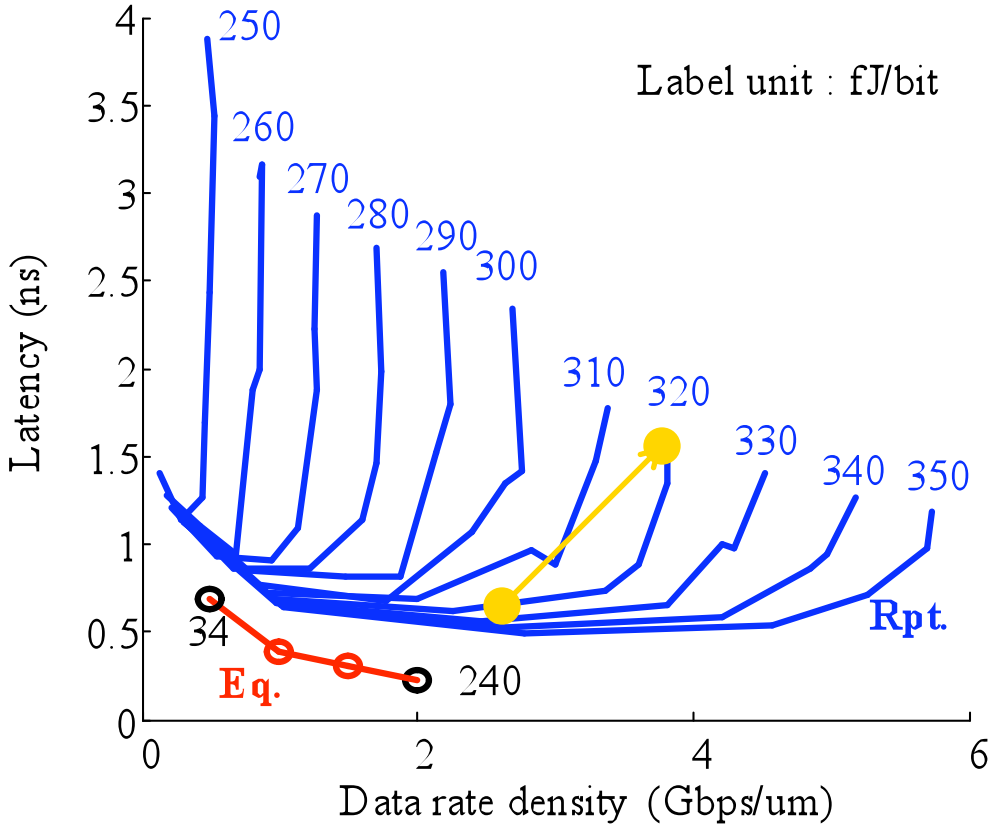
For a given target distance

- Data rate density = (Data rate)/ (cross-sectional width)
- Energy per bit
- Latency



- In general, we cannot normalize these metrics by length.

Trade-off: repeated interconnects

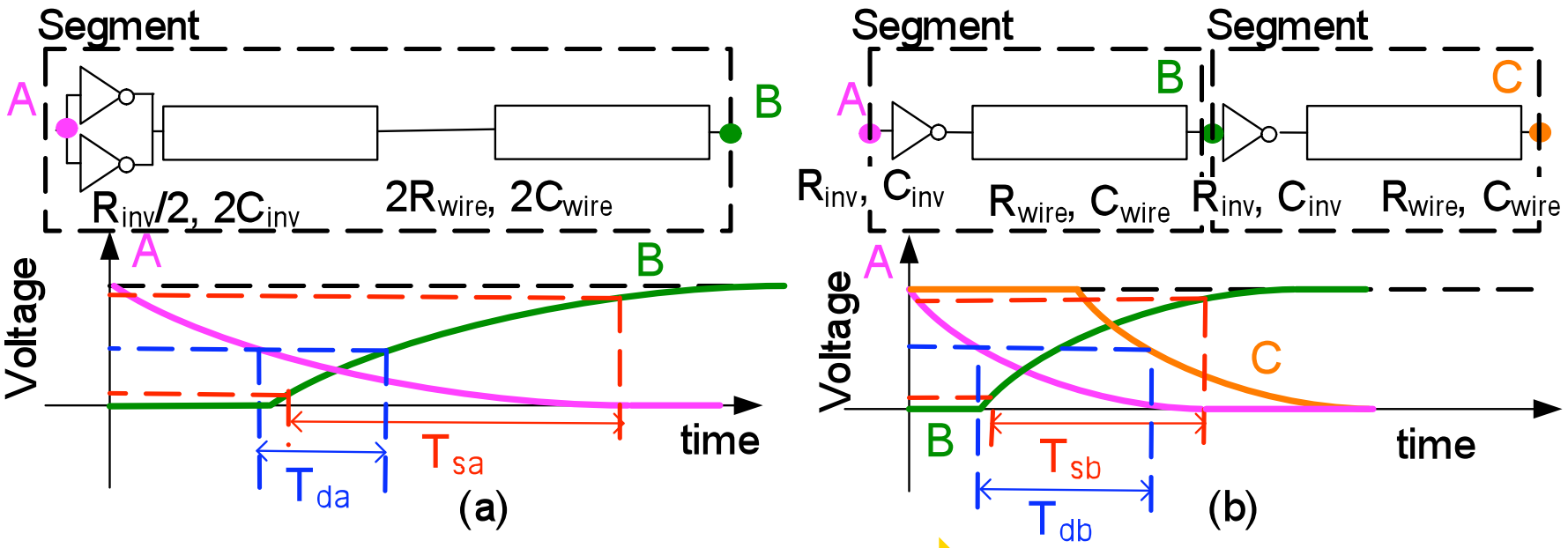


1cm long
32nm technology
aggressively scaled
(http://ptm.asu.edu)

KIM D&T 2008

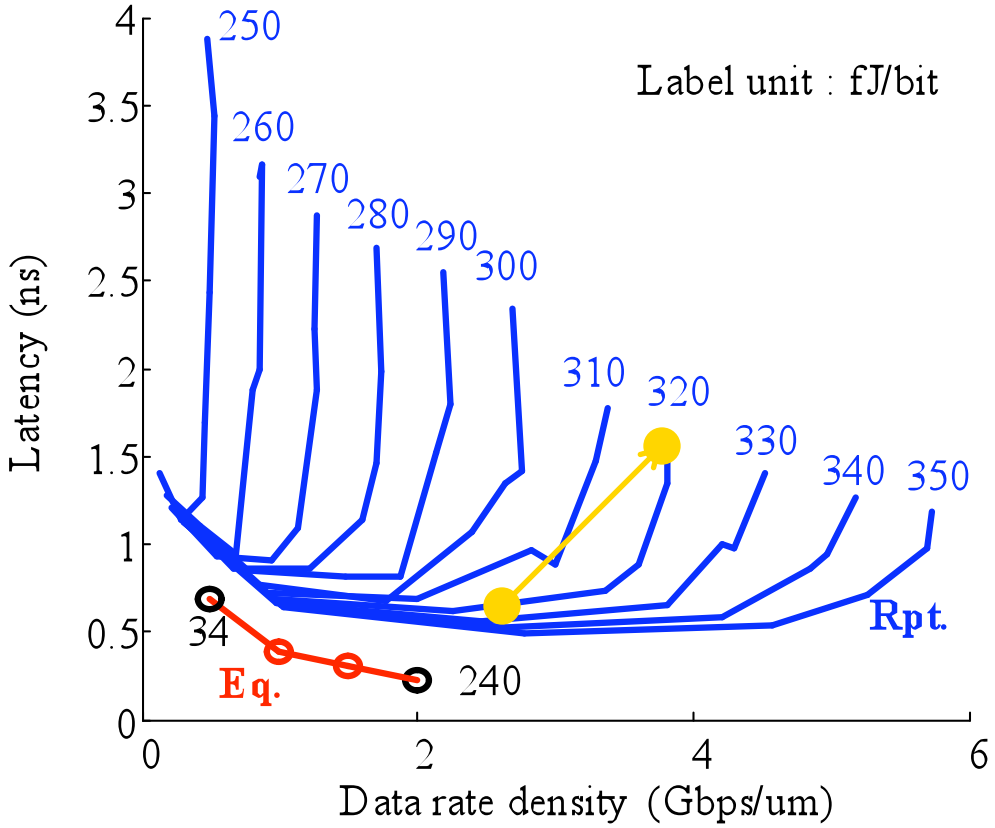
- Repeater trade-off: three dimensional surface.
  - Wires and circuits are jointly optimized.

Trade off: repeated interconnects



- Same energy per bit: same capacitance
- Larger data rate density : Tsb < Tsa
- Larger latency : Tdb > Tda

Trade-off: repeated interconnects



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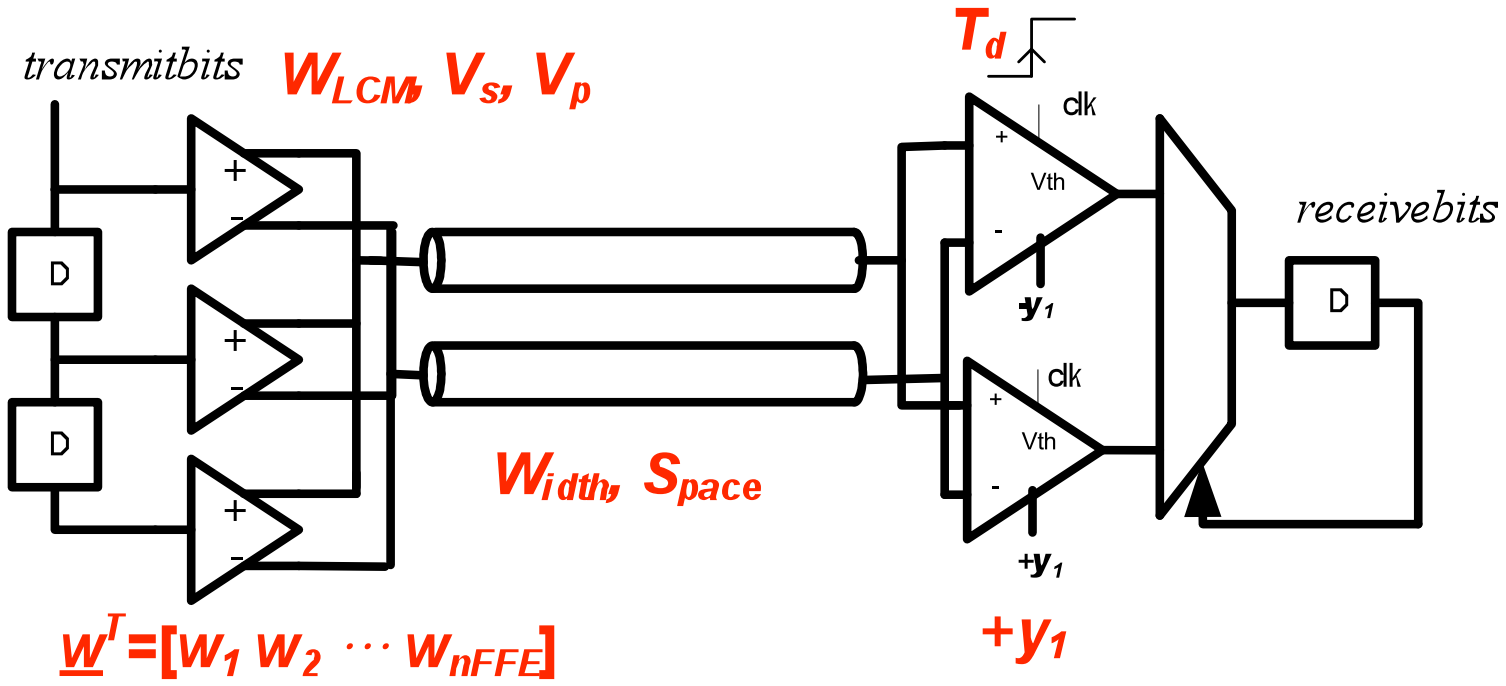
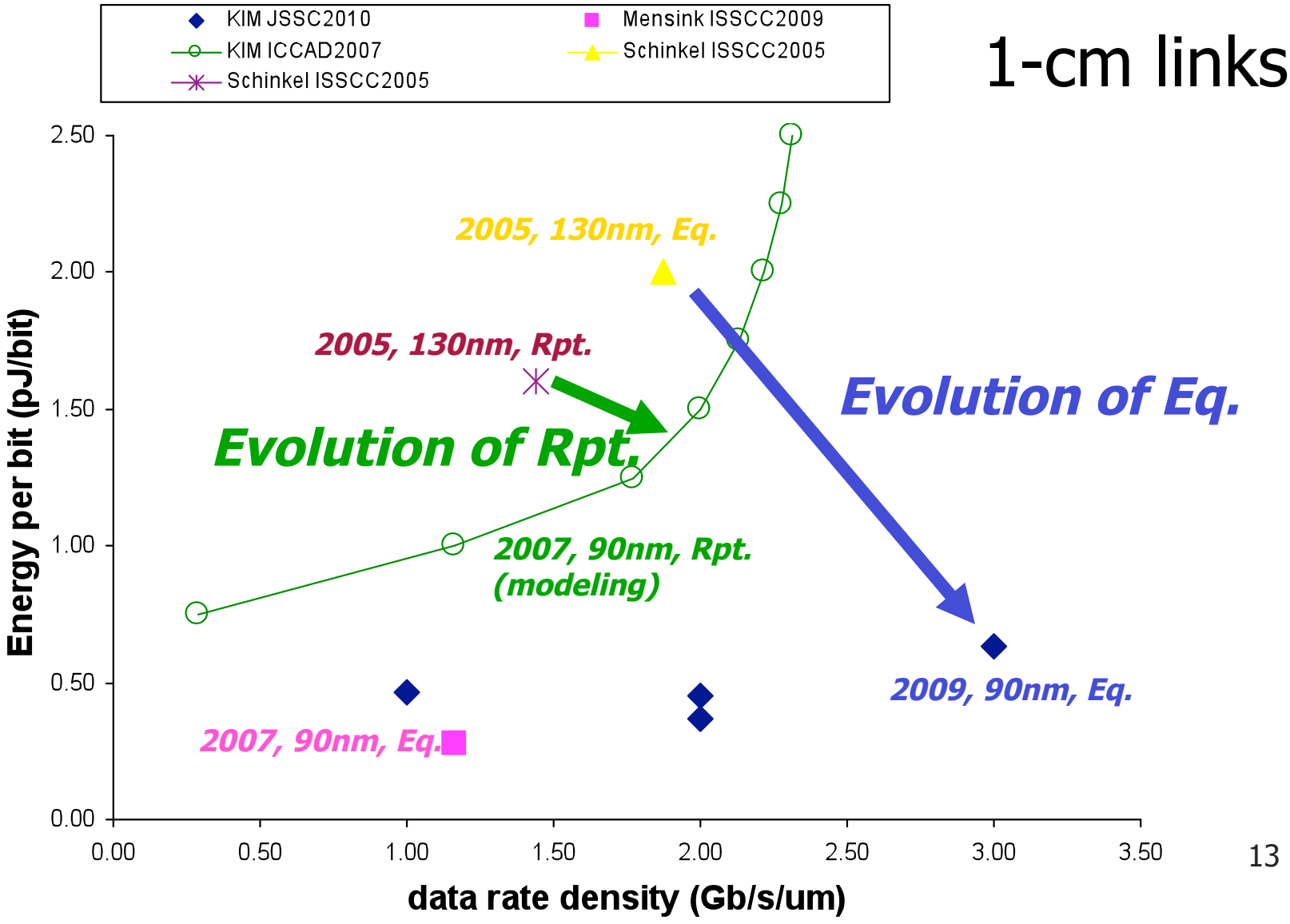
Equalized Interconnects

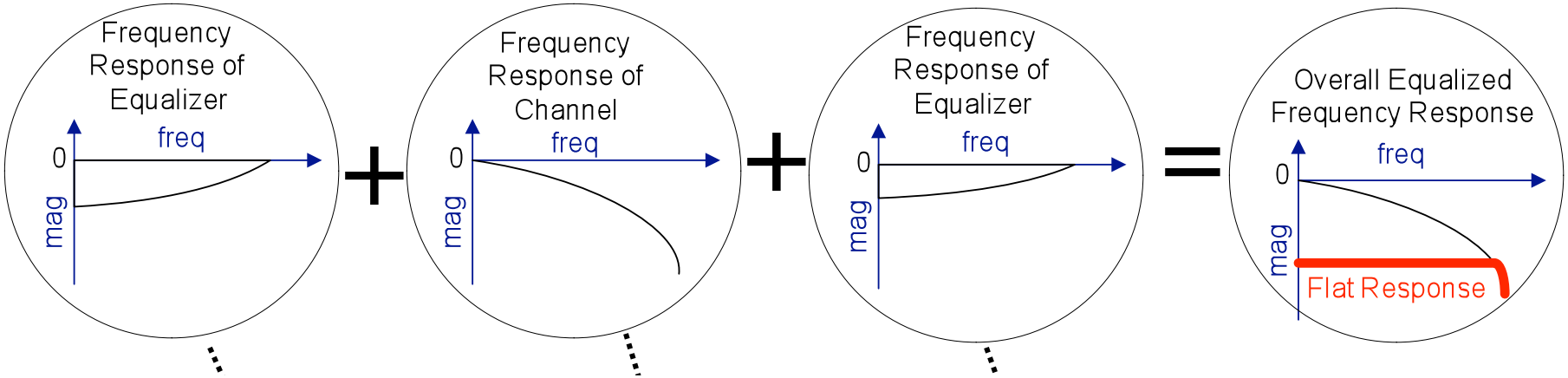


- Potentially lower power and higher data rate than repeaters.

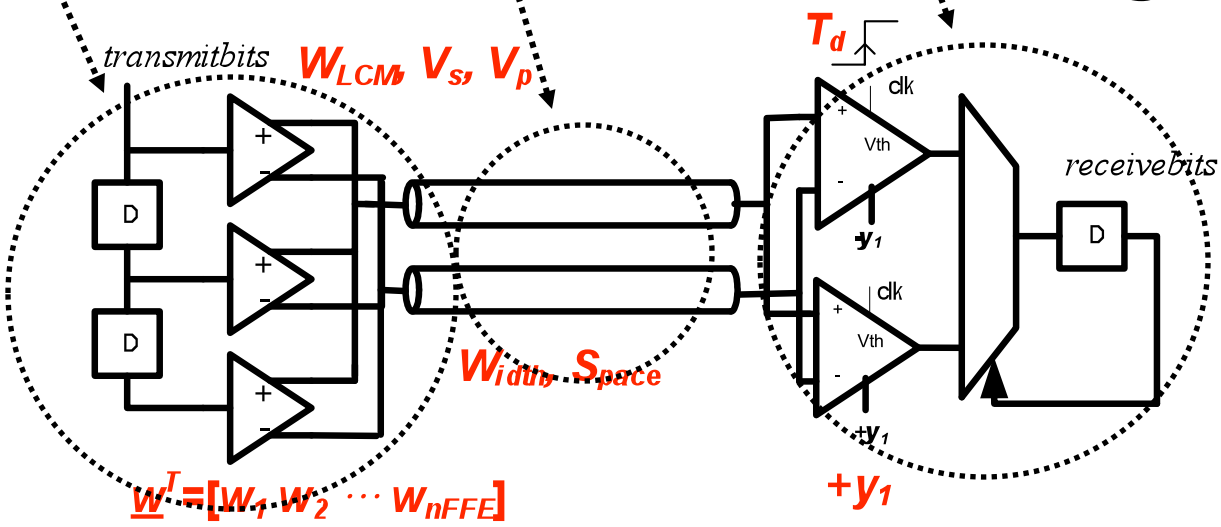
Evolution of equalized interconnects



Review: equalization in frequency domain



Tx: HPF ***Channel: LPF*** ***Rx: HPF*** ***Overall: flat higher data rate***

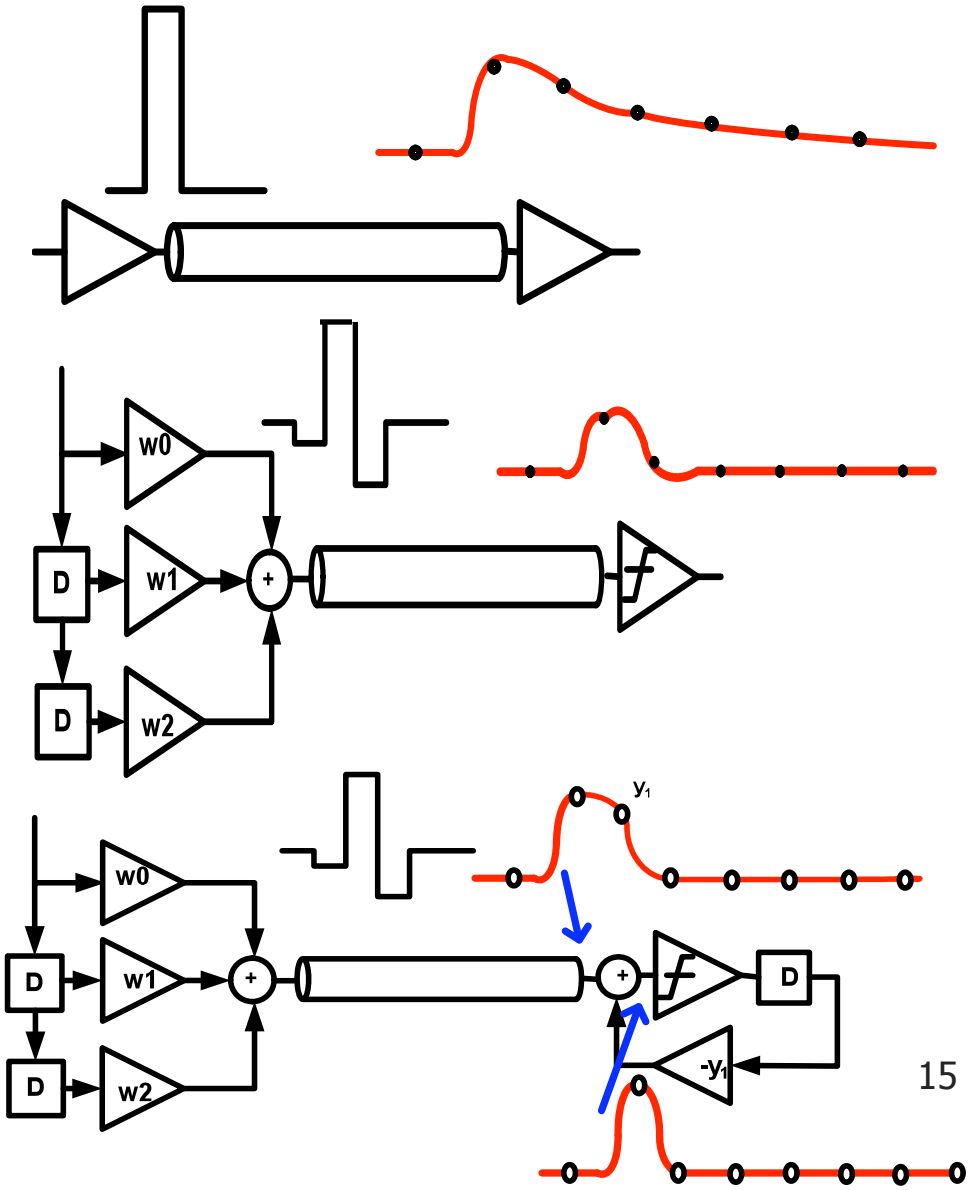


Review: equalization in time domain

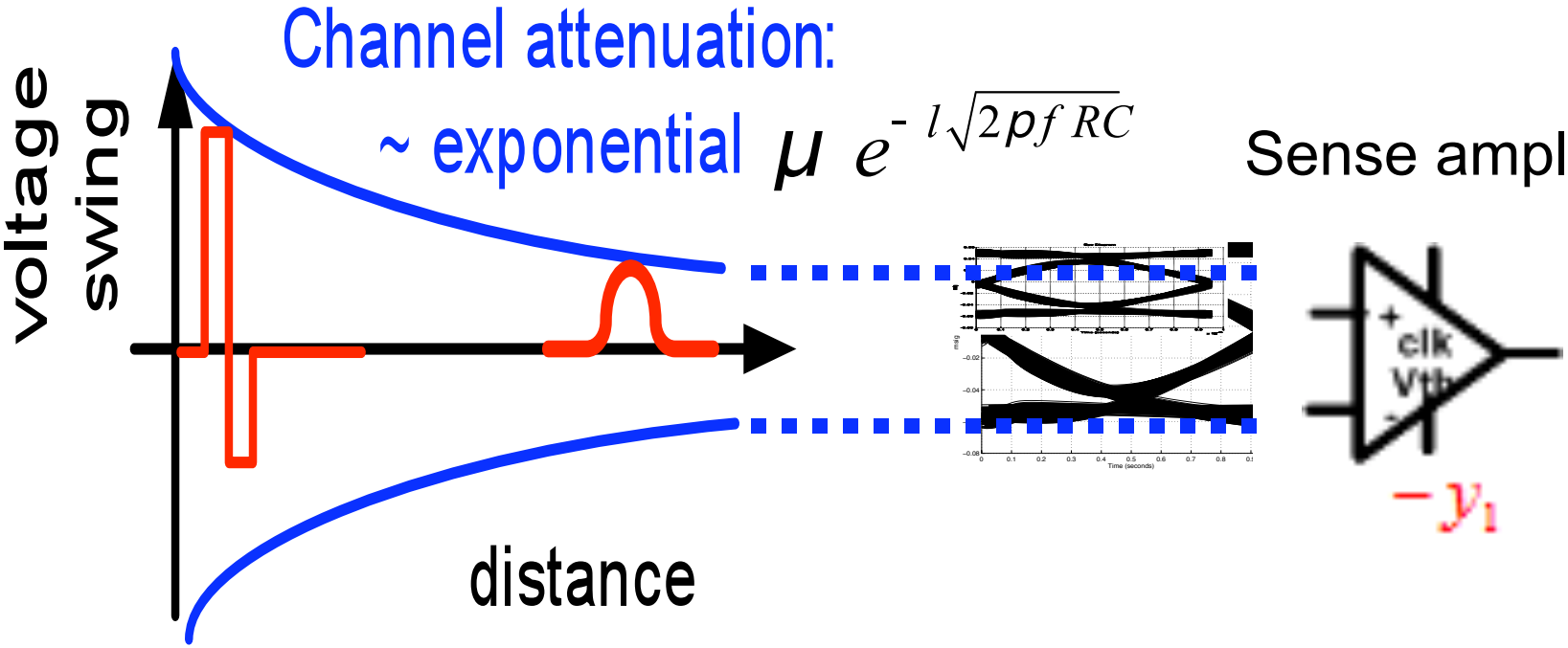
No equalization

Feed forward equalization (FFE)

FFE + decision feedback equalization (DFE)

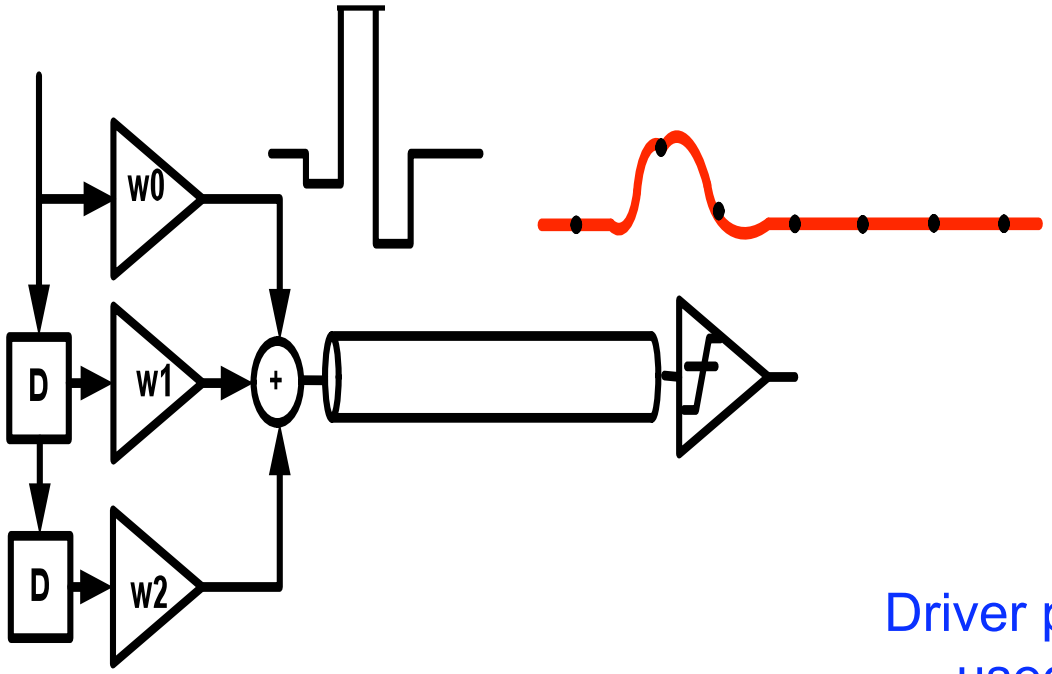


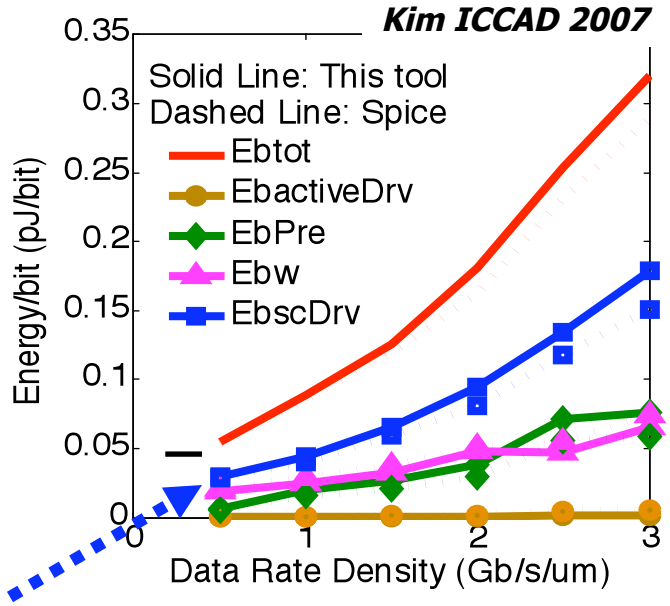
Trade-off: equalized interconnect



- Rx can sense small voltage ~ 100mV.
- Tx swing is adjusted for target eye size (constant).
- Tx swing is proportional to attenuation.
- By rule of thumb, energy per bit cost $\mu\ e^{l\sqrt{2pfRC}}$

Review: power consumption of equalization



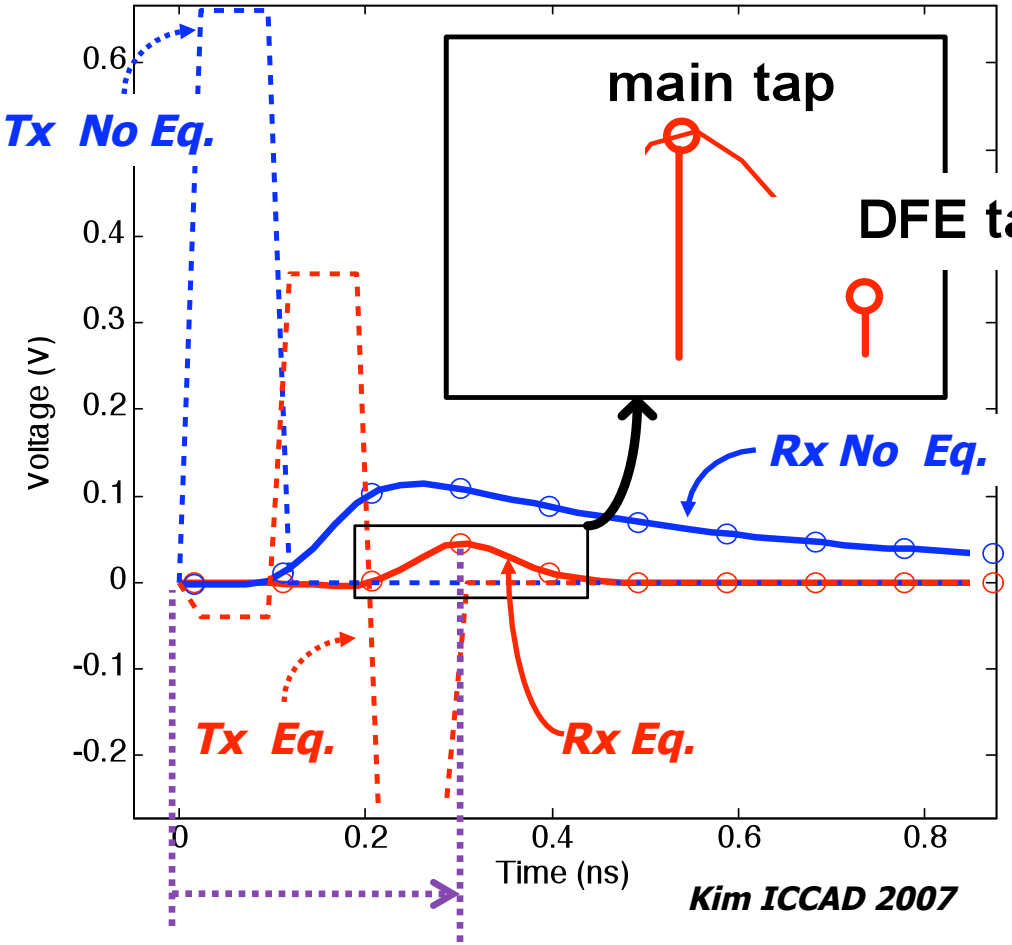


Driver power overhead:
used be > 50% ➔ <25%)

- Power overhead required
  - New topologies greatly reduced power overhead.
    - Eg.) Kim ISSCC2009, Mensink ISSCC2007, …

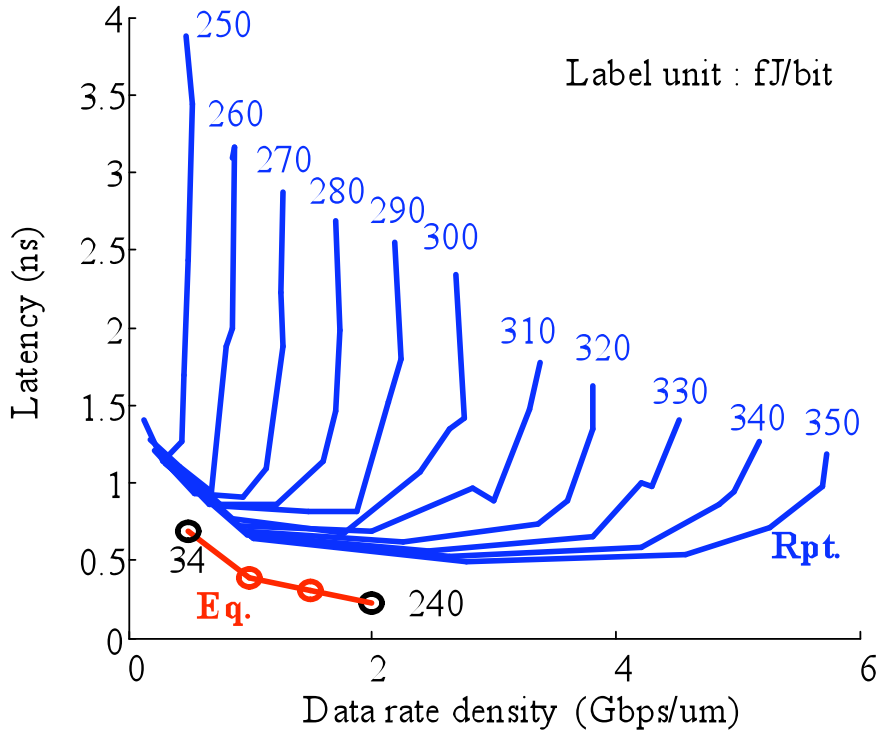
Trade off: equalized interconnect

Equalized and unequalized pulses corresponding for isolated '1' at Tx and Rx (90nm technology)



- For a given data rate density tareget, latency is fixed.
- The channel determines equalized Tx and Rx waveforms and the proper sampling time T_d (latency).

Trade-off: equalized interconnects



1cm long
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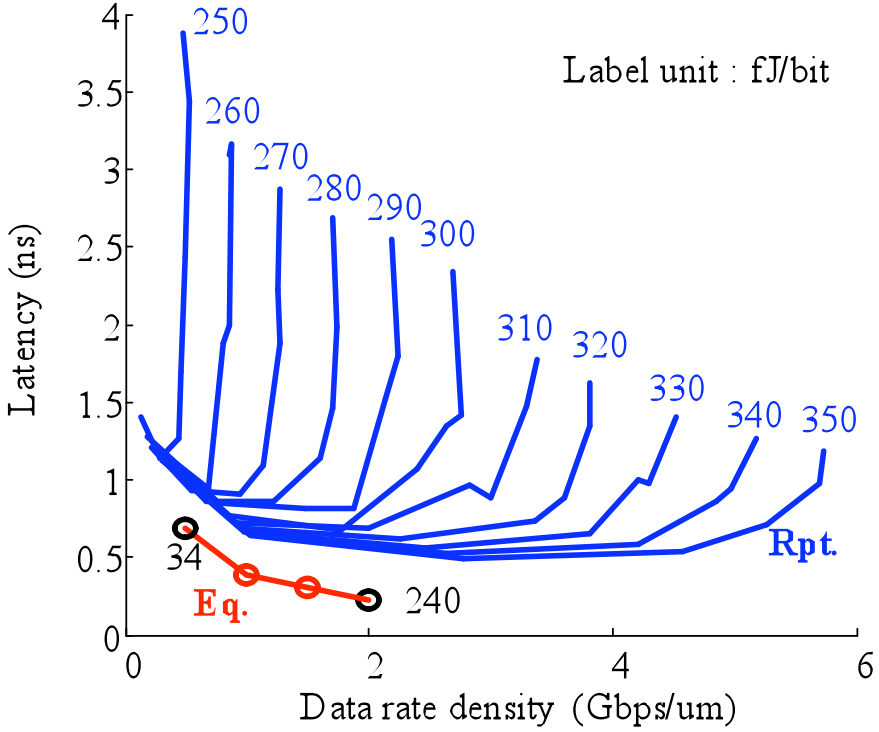
KIM D&T 2008

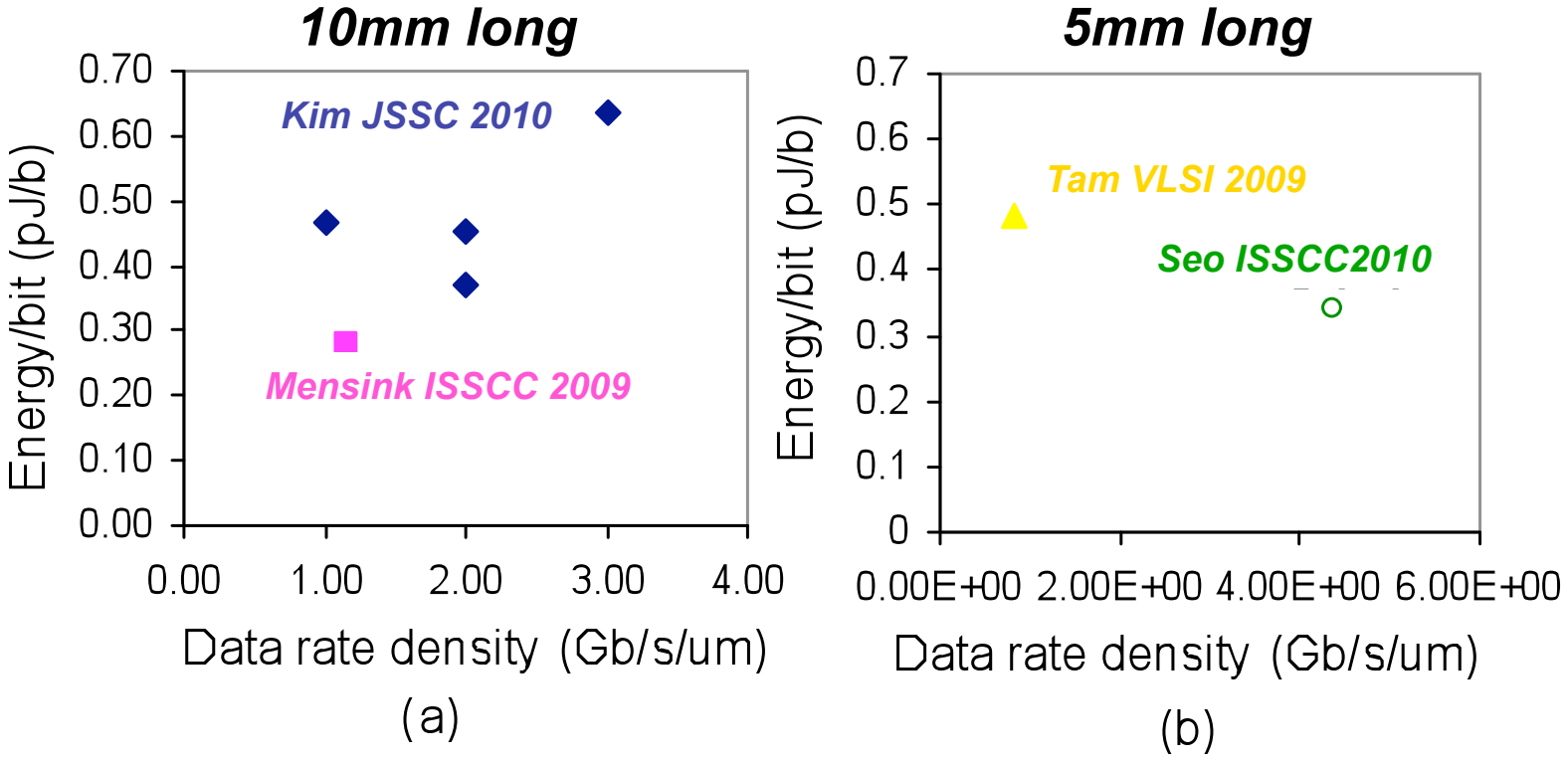
- Trade-off curve of equalized interconnect is 3-dimensional line.

The winning interconnect



- Depends on application requirements.
- In general,
  - Rpt. wins in short distance (<5mm) or long distance applications (>10mm).
  - Eq. wins in medium distance (5mm-10mm).

Current status: equalized interconnects



- 2-3Gb/s/um with 400fJ/b-600fJ/b over 10mm in 90nm CMOS ASIC technology.
- We can expect further improvement in 22nm high-performance processor technology.

Conclusion

- To set the right direction of nanophotonics, we must compare them to the winning electrical interconnects, either repeated or equalized.
- Fair comparison metrics
  - data rate density, energy per bit, and latency.
- A repeated interconnect trade off is a 3-dimensional surface.
  - latency ←→ data rate density
- Equalized interconnects provide better energy efficiency for the same performance in many situations than repeated ones.
- There is no absolute winner.
  - In general, an equalized interconnect is better for 5-10mm distance.