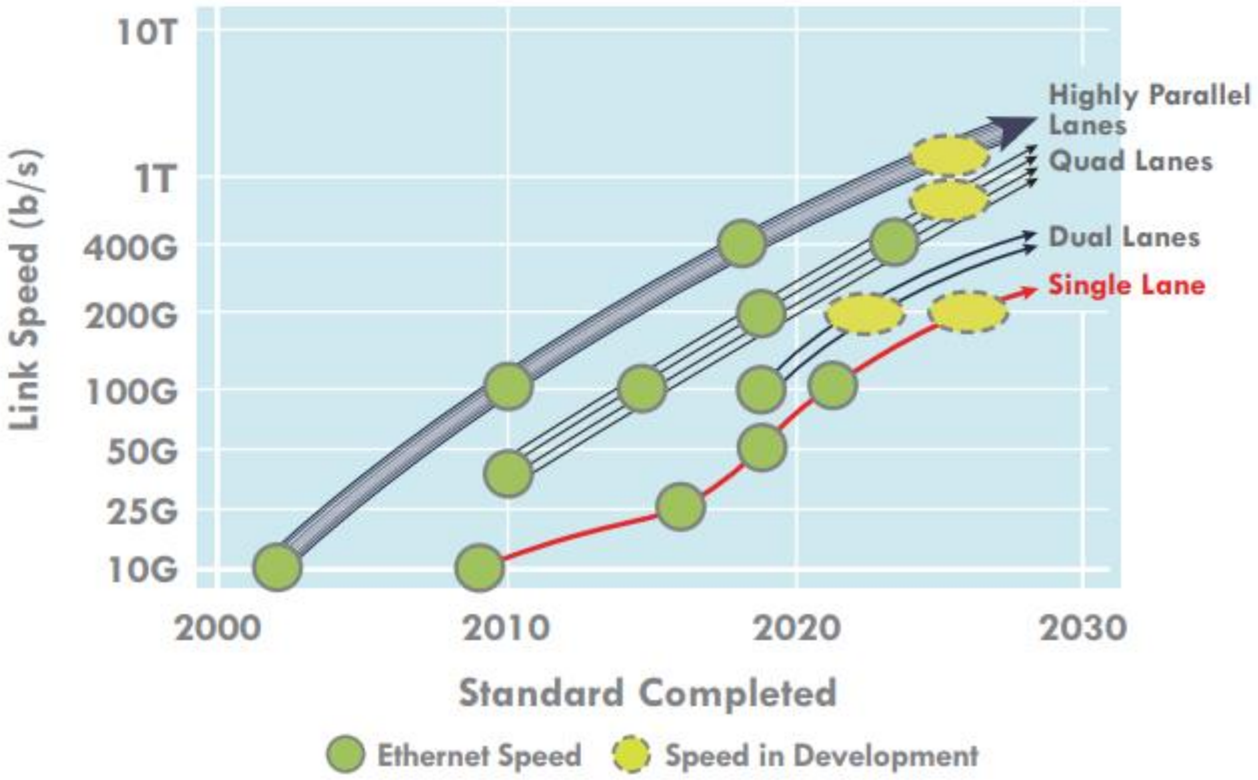
Silicon Photonics and Electronics for High-Speed Transceivers

Peter Ossieur, on behalf of the IDLab-Design and Silicon Photonic colleagues

Optical transceivers for data center applications

Upcoming targets - pluggable transceivers

- Ethernet Alliance 2022 roadmap



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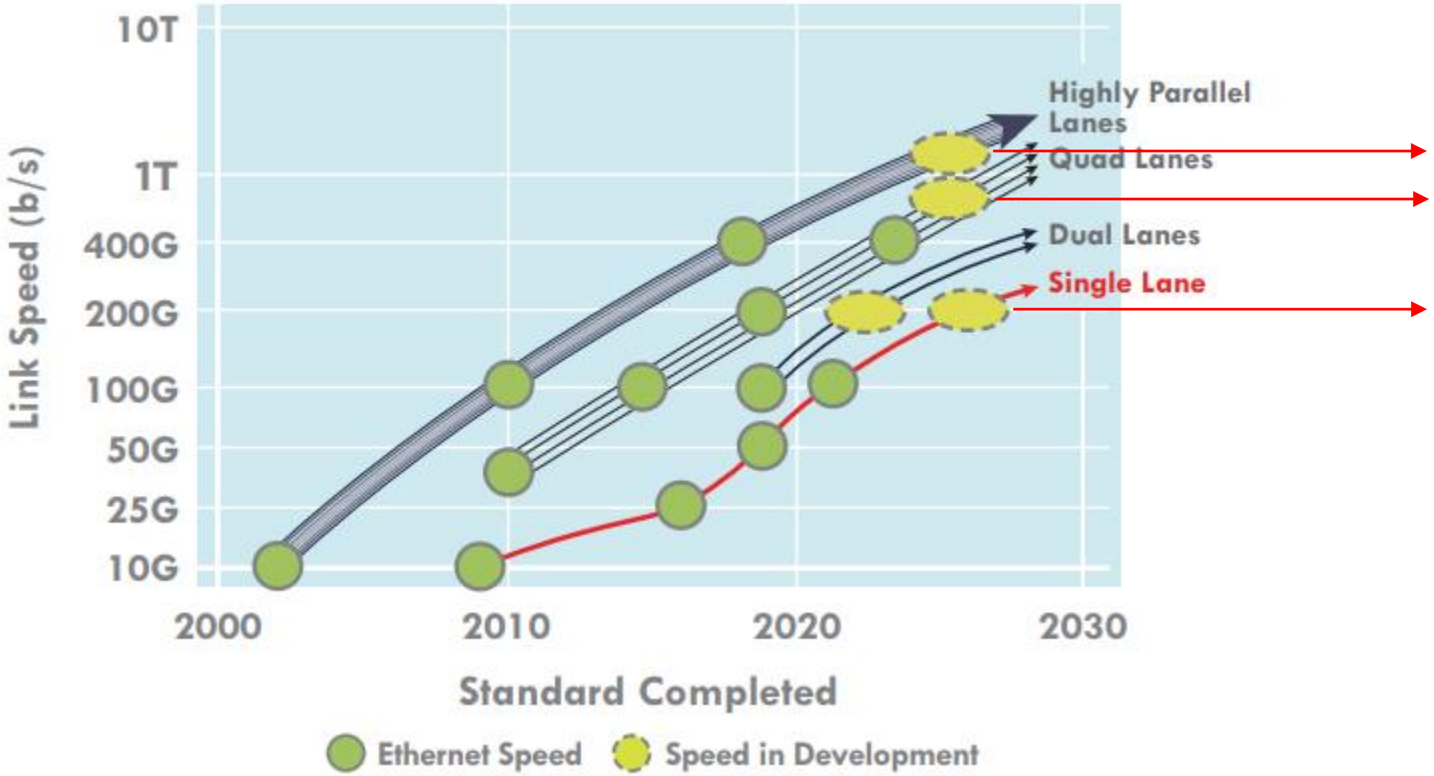
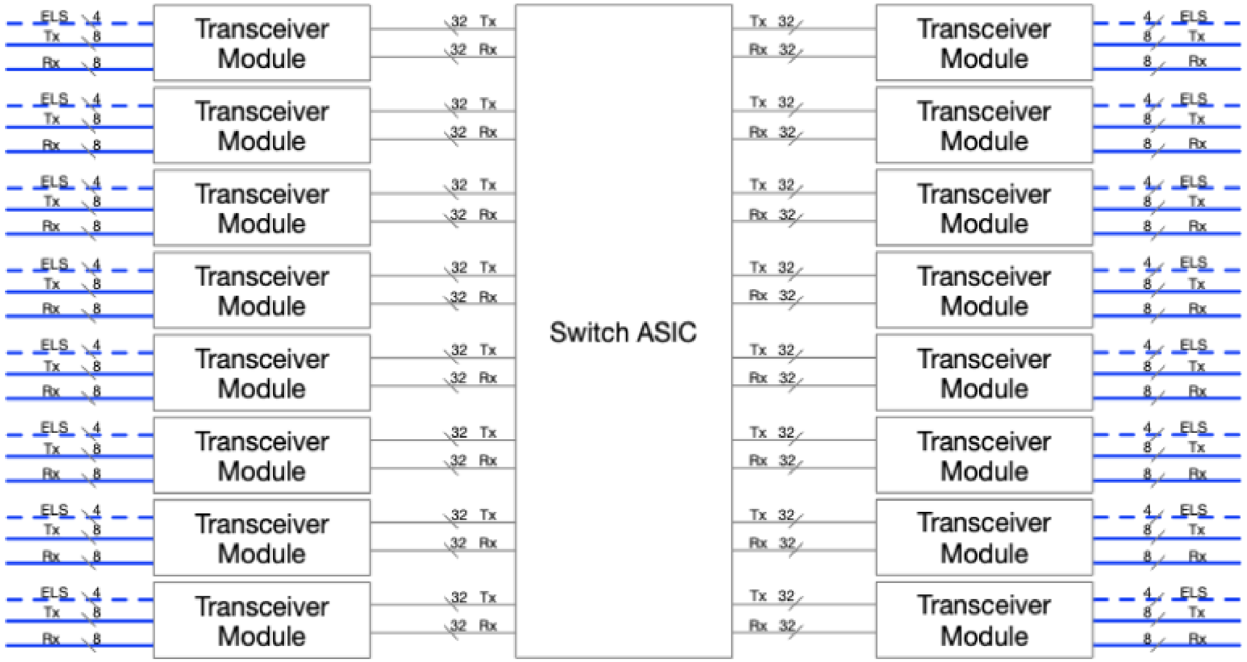


IEEE P802.3df 200Gb/s, 400Gb/s, 800Gb/s and 1.6Tb/s Ethernet Task Force

Optical transceivers for data center applications

Upcoming targets - co-packaged transceivers

- Co-packaged Optics Collaboration - www.copackagedoptics.com and OIF
  - 3.2Tb/s Optical Module to support 51.2Tb/s switch: 16 modules surrounding switch ASIC



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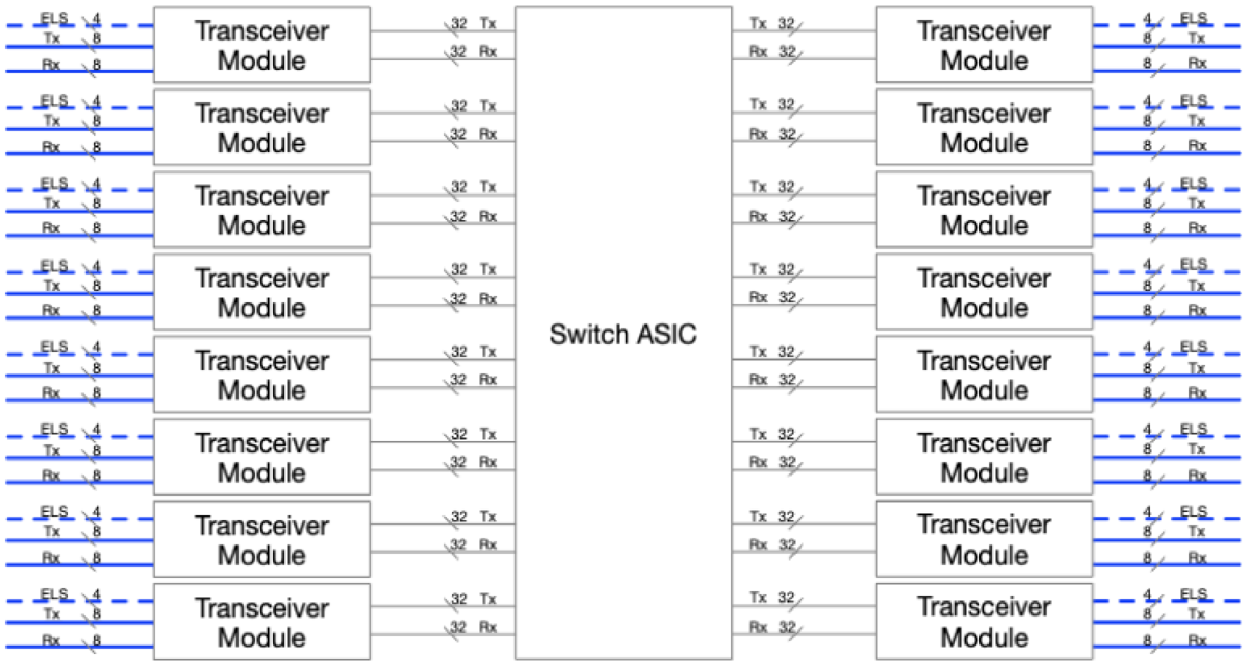
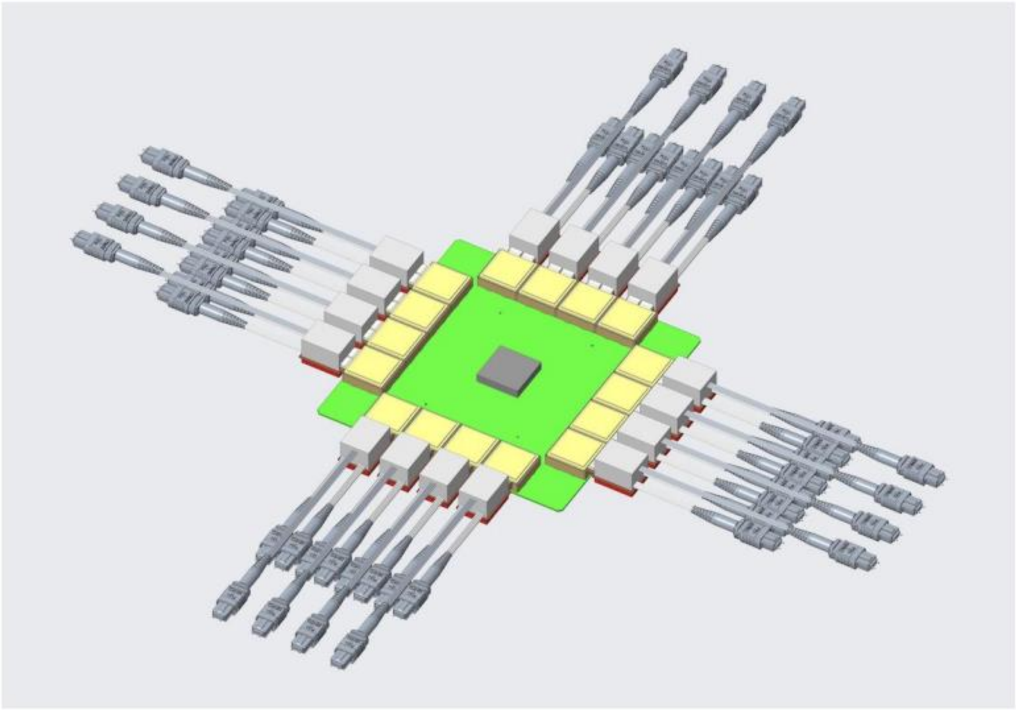
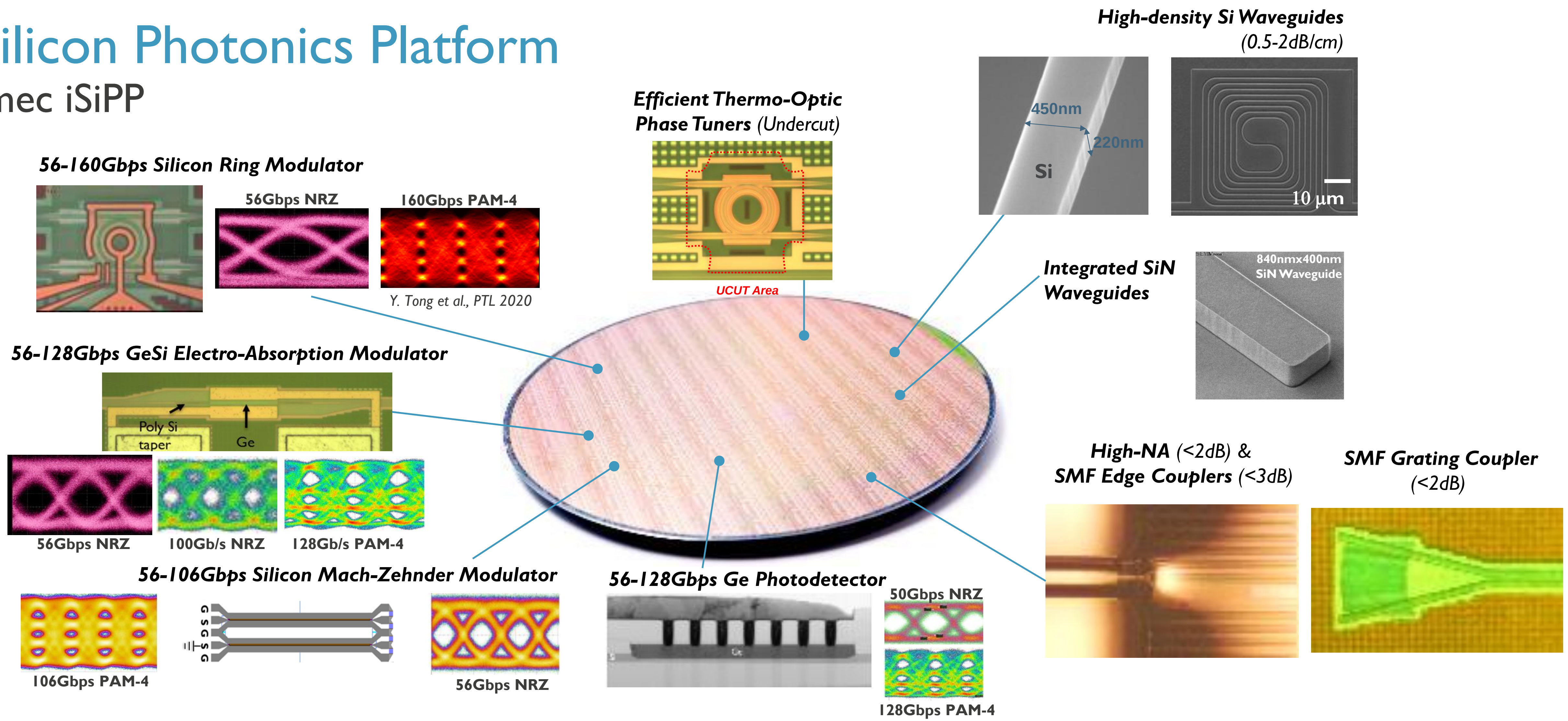




Silicon Photonic Platforms for High-speed Optical Transceivers

Silicon Photonics Platform

imec iSiPP

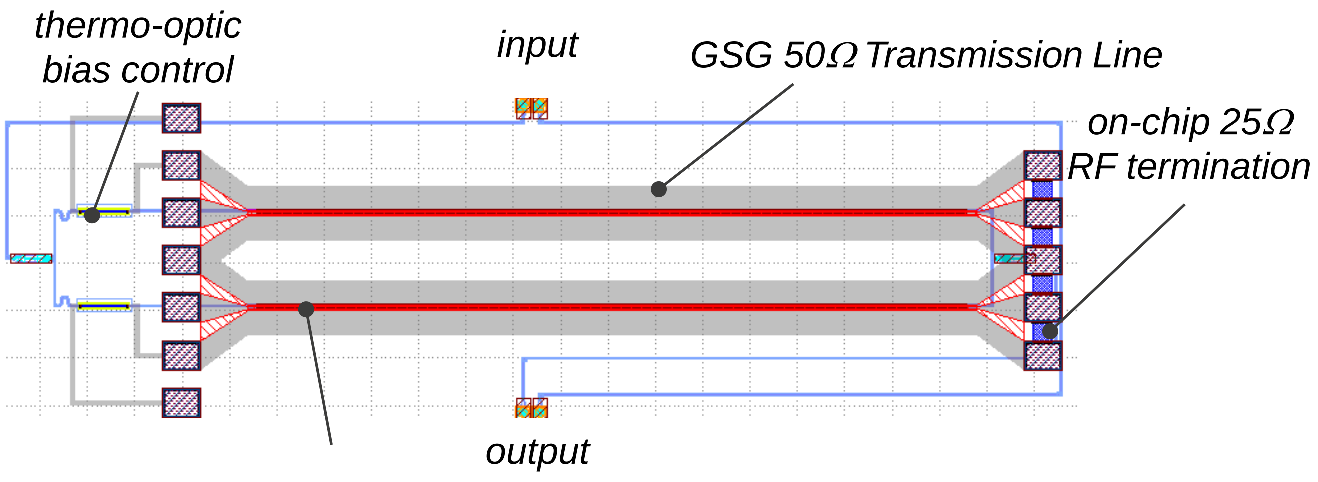


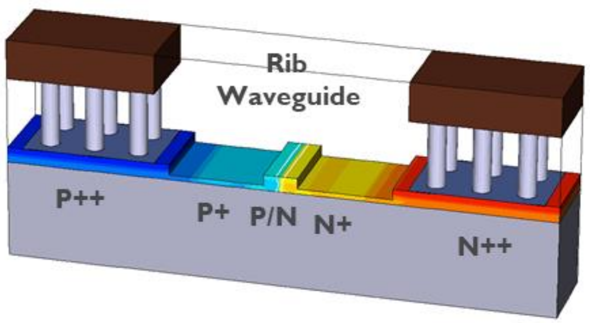
- Co-integration of passive and active components supporting 56-128Gb/s lane rates
- Most components are available for O-band and C-band operation

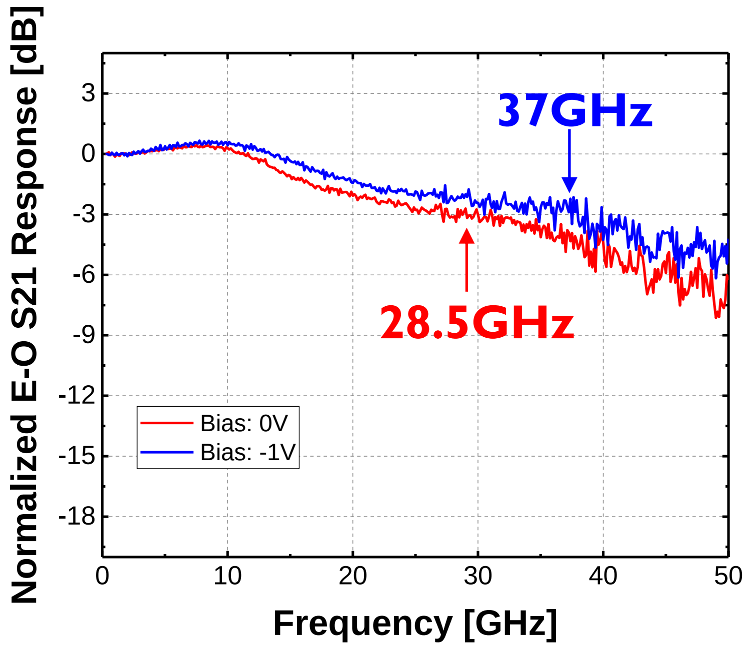
High-Speed Silicon Photonic Modulators - example demonstrations

Carrier-depleted Mach-Zehnder Modulator

- Reference O-band design in IMEC PDK







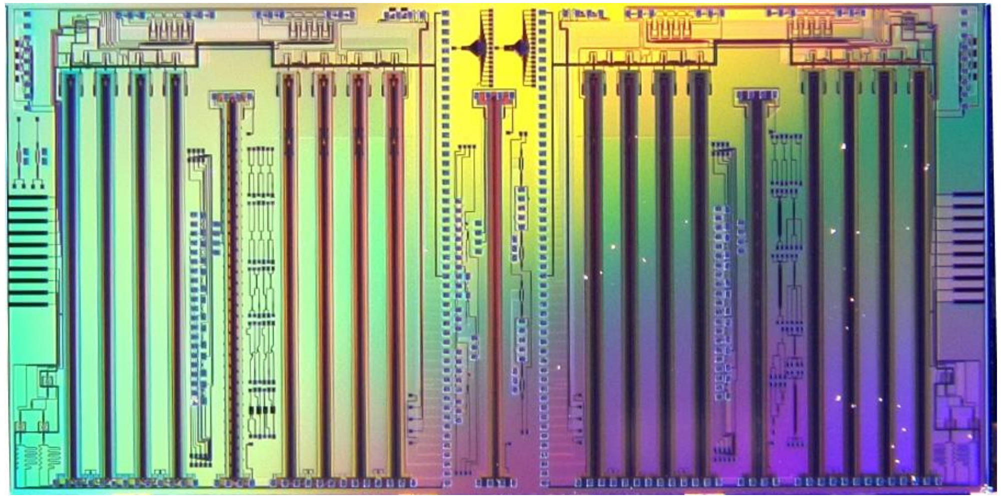
Traveling-Wave MZ Modulator	Value	Unit
Phase-shifter length	1.5	mm
DC Insertion Loss @ 0V	~2	dB
Vπ @ 0V	10.5	V
S21 Bandwidth @ 1V	37	GHz
S11 (0.1 GHz—1 GHz) @0V	< -15	dB

High-Speed Silicon Photonic Modulators - example demonstrations

Carrier-depleted Mach-Zehnder Modulator

- Dual-polarization IQ modulator for coherent transceiver applications
  - Features Optical Equalizer as additional means to trade V_π versus bandwidth
  - On-going development work

	Length [mm]	Vπ [V]	IL [dB]	f3dB [GHz]
Regular MZM				
MZM w. OEQ				
MZM				



Prototype PIC with O-band and C-band dual-polarization IQ modulators

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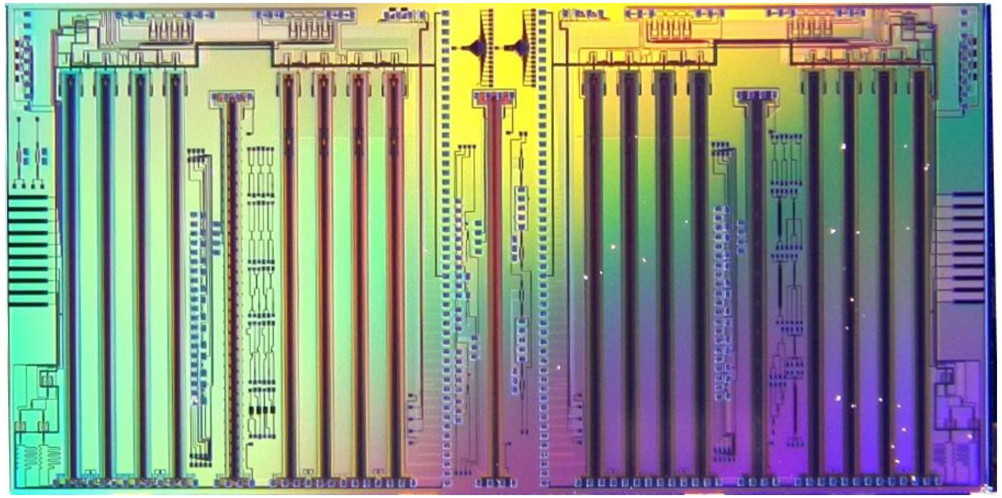

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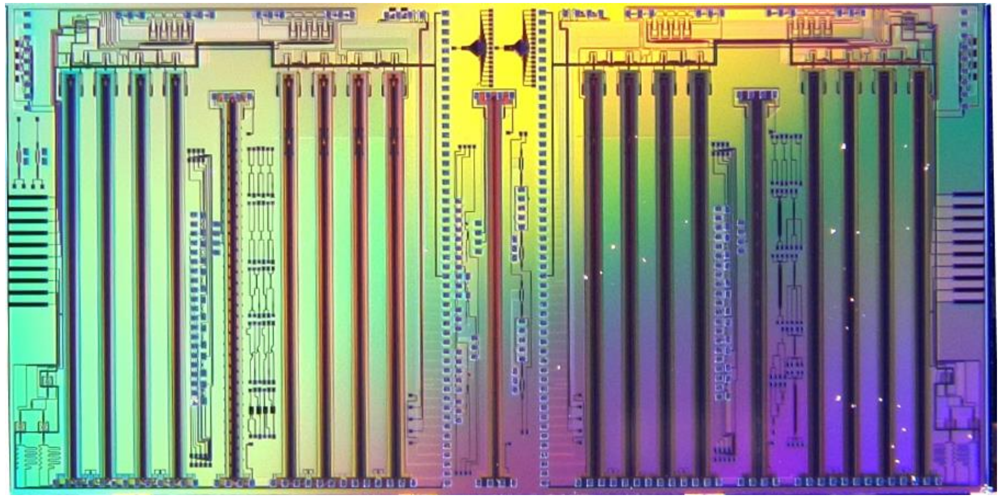
MZM				



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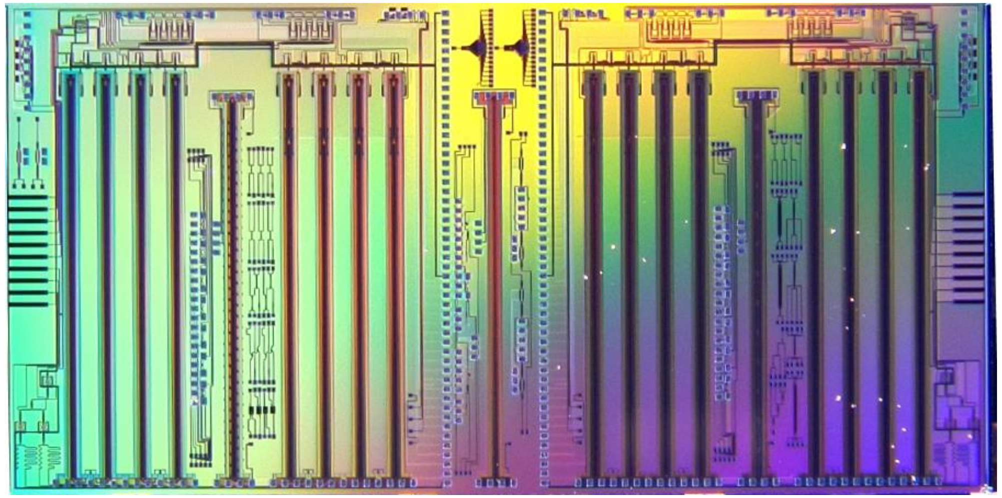
MZM	3.1	6.13	4.96	32.4



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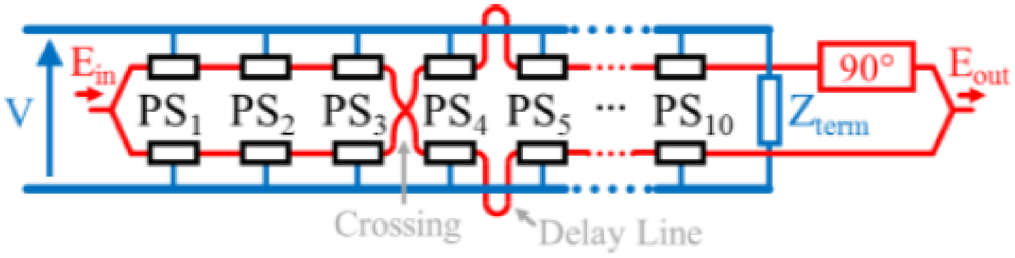
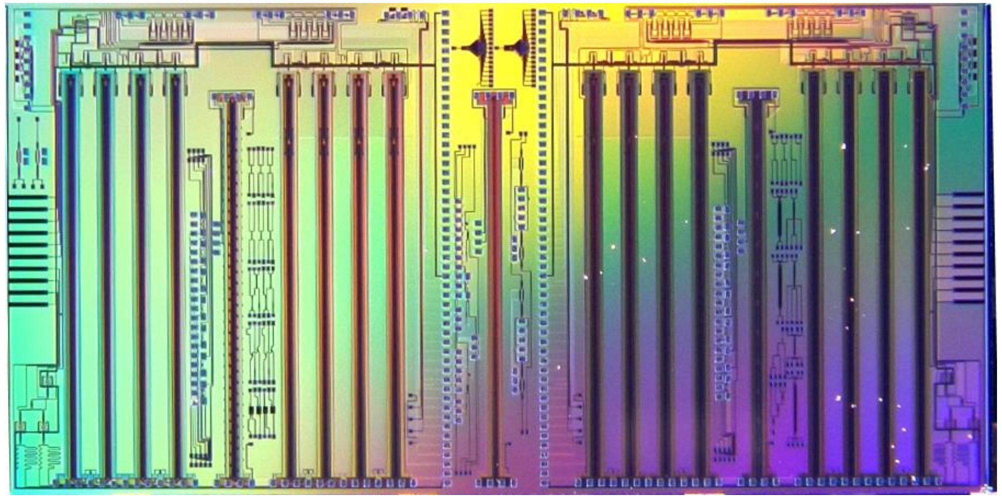
- View MZM as tapped delay line (FIR filter) (pat.)
  - Introduce taps through choice of phase shifter length sections
  - Introduce crossings for tap sign inversions





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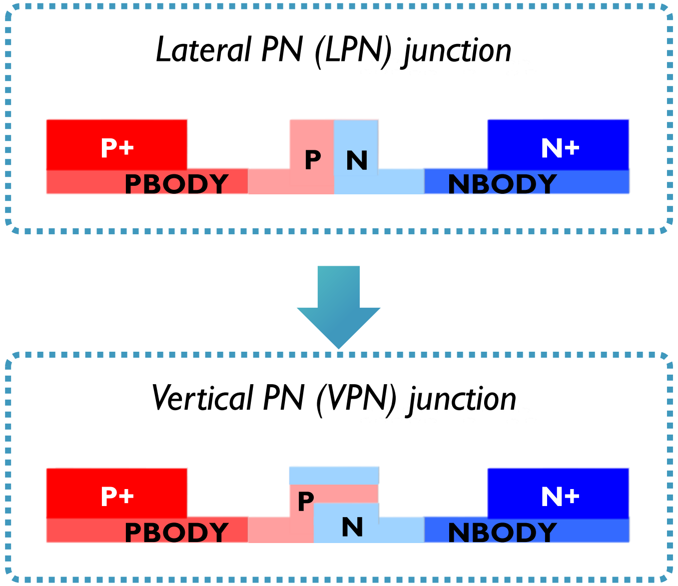
High-Speed Silicon Photonic Modulators - example demonstrations

Vertical pn-junction ring modulator

- From lateral to vertical pn junction

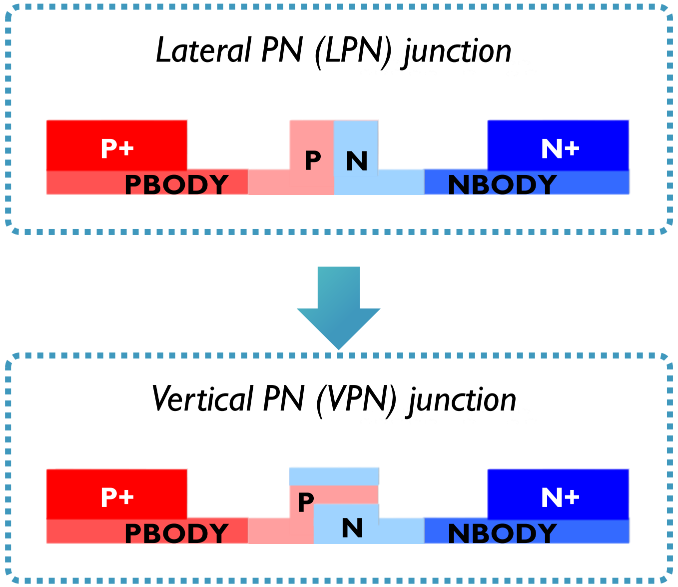


Y. Ban et al., IEEE Optical Interconnects Conference 2019: "Low-Voltage 60Gb/s NRZ and 100Gb/s PAM4 O-band Silicon Ring Modulator", OI conference 2019.

High-Speed Silicon Photonic Modulators - example demonstrations

Vertical pn-junction ring modulator

- From lateral to vertical pn junction: improved modulation efficiency



Diode Type	$V_\pi L_\pi$ (V.cm)	Loss (dB/cm)	ME (pm/V)
LPN	0.71	97	30
VPN	0.42	86	47

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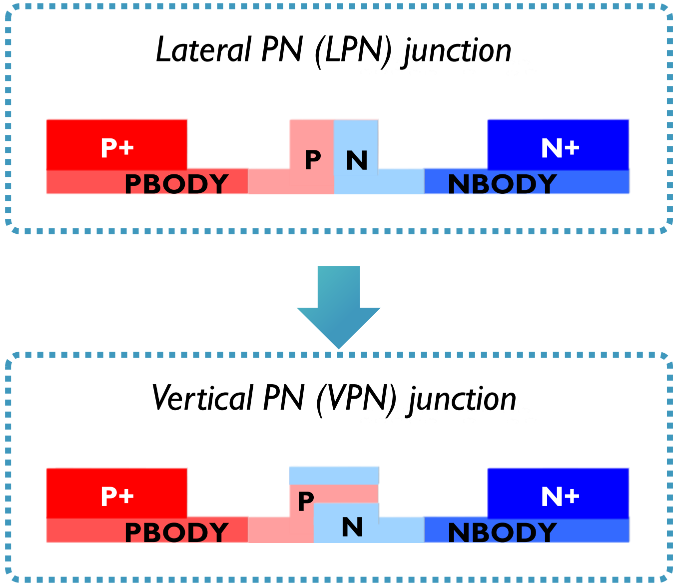

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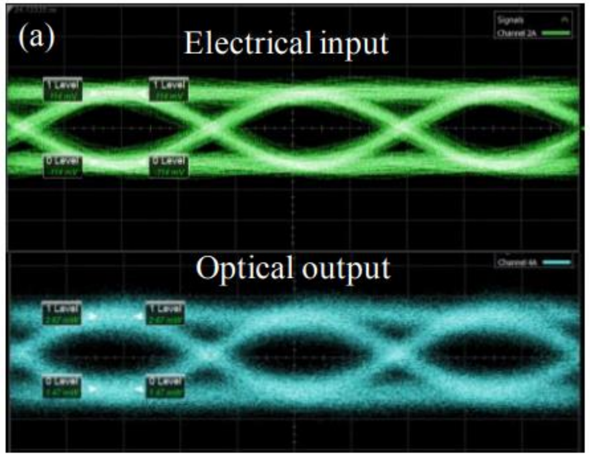
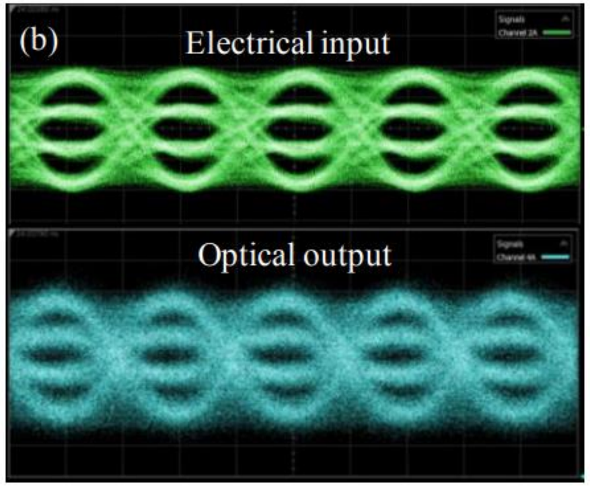


60Gb/s NRZ



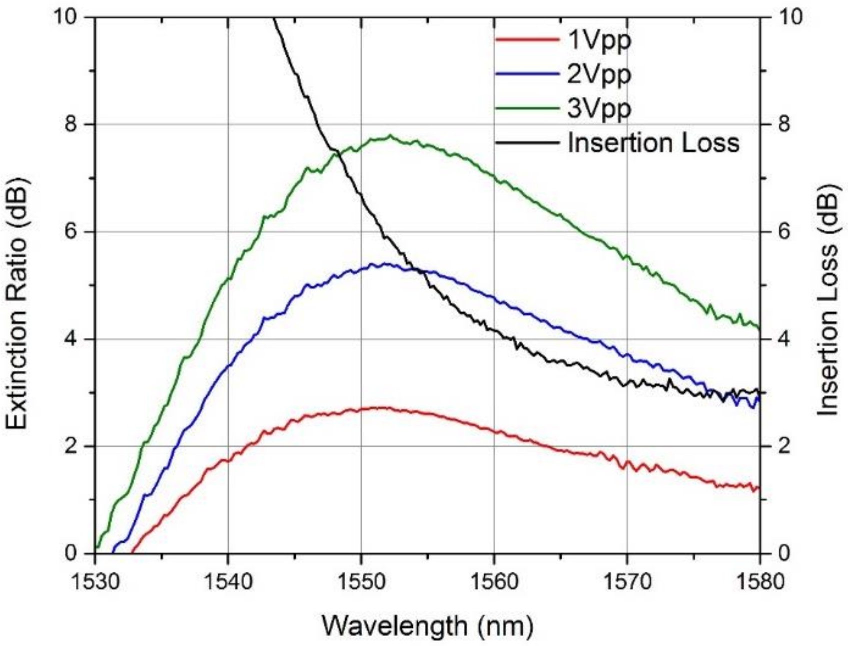
50Gbaud PAM-4

Y. Ban et al., IEEE Optical Interconnects Conference 2019: "Low-Voltage 60Gb/s NRZ and 100Gb/s PAM4 O-band Silicon Ring Modulator", OI conference 2019.

High-speed Silicon Photonic modulators

C-band GeSi Electro-absorption modulator

- Franz-Keldish effect modulator on Silicon Photonic platform



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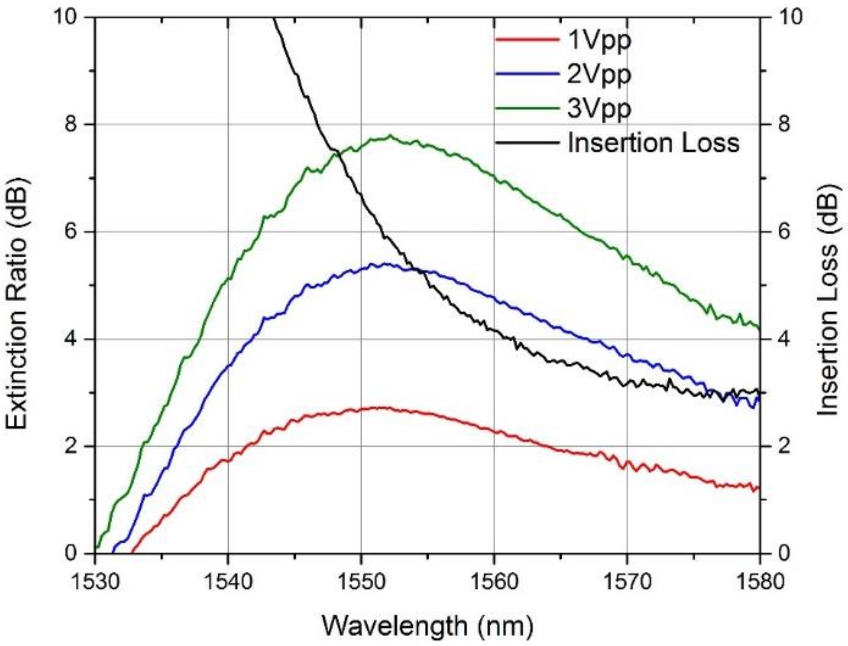
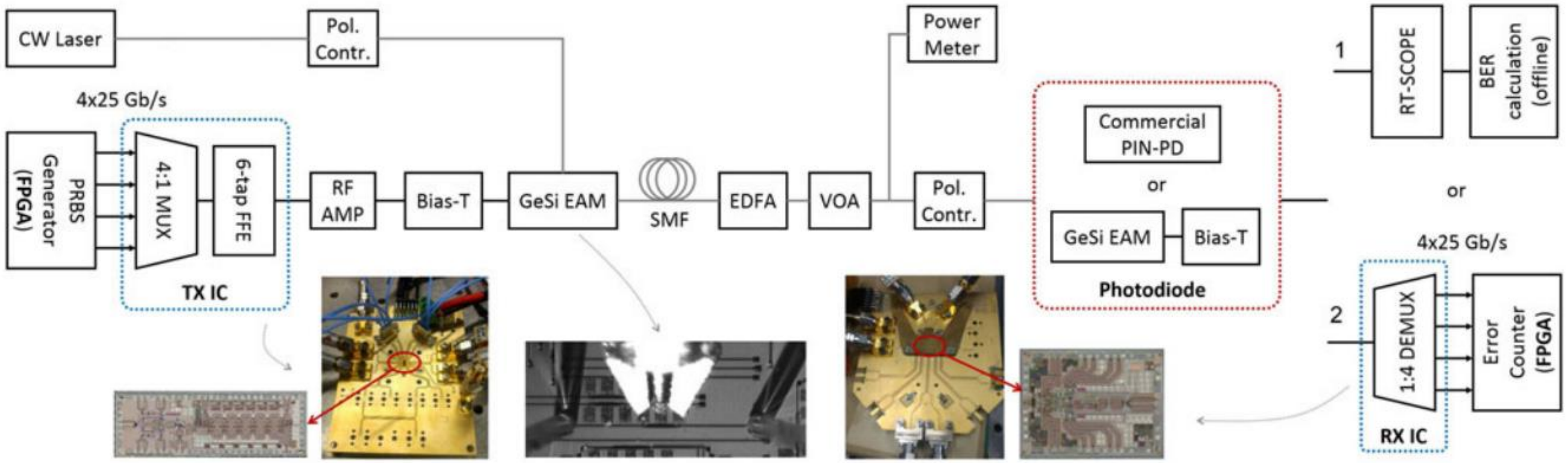
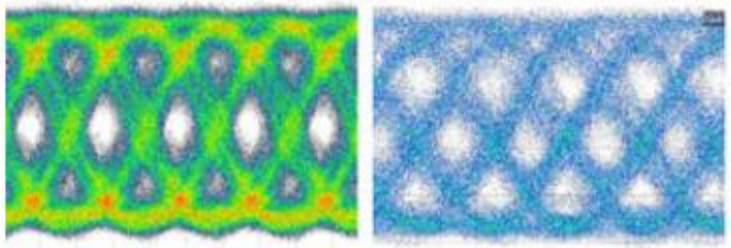
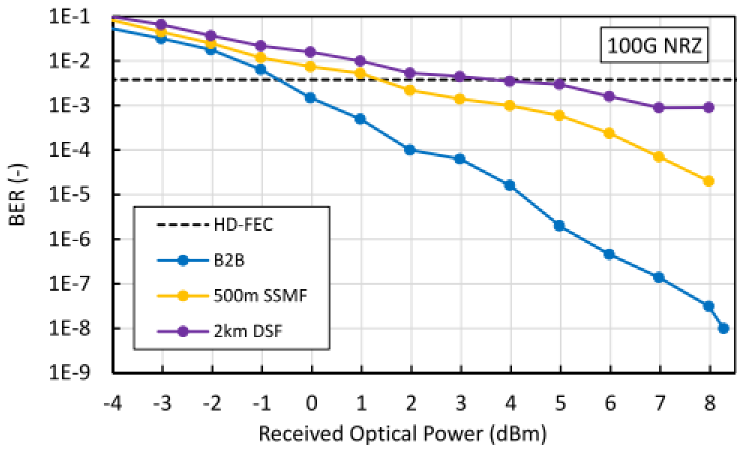




100Gb/s NRZ



B2B **500m**

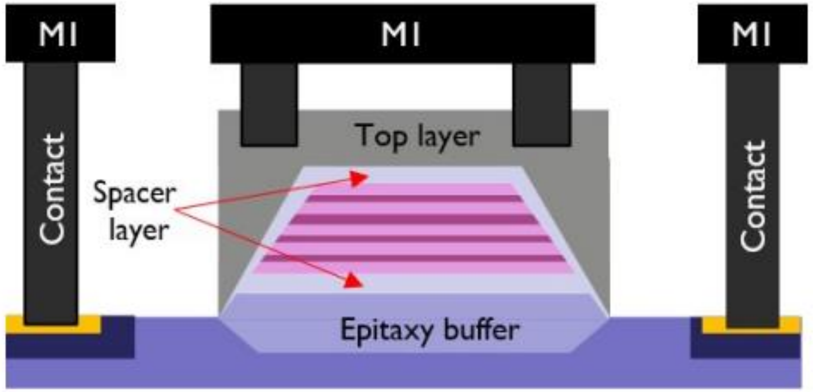


Silicon Photonics Platform

On-going developments

SiPho-G
Advanced GeSi components for next-generation silicon photonics applications

- O-band QCSE electro-absorption modulator integrated and waveguide-coupled in a Silicon Photonic platform



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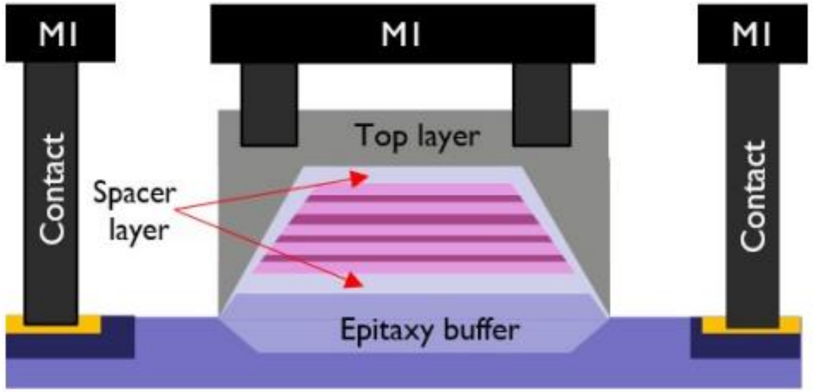
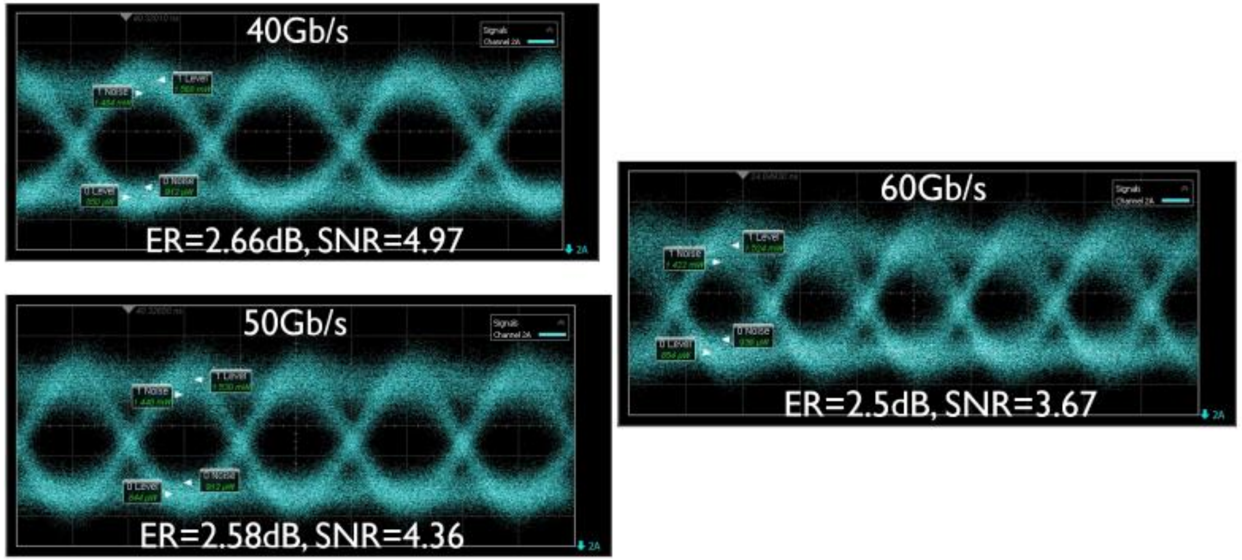


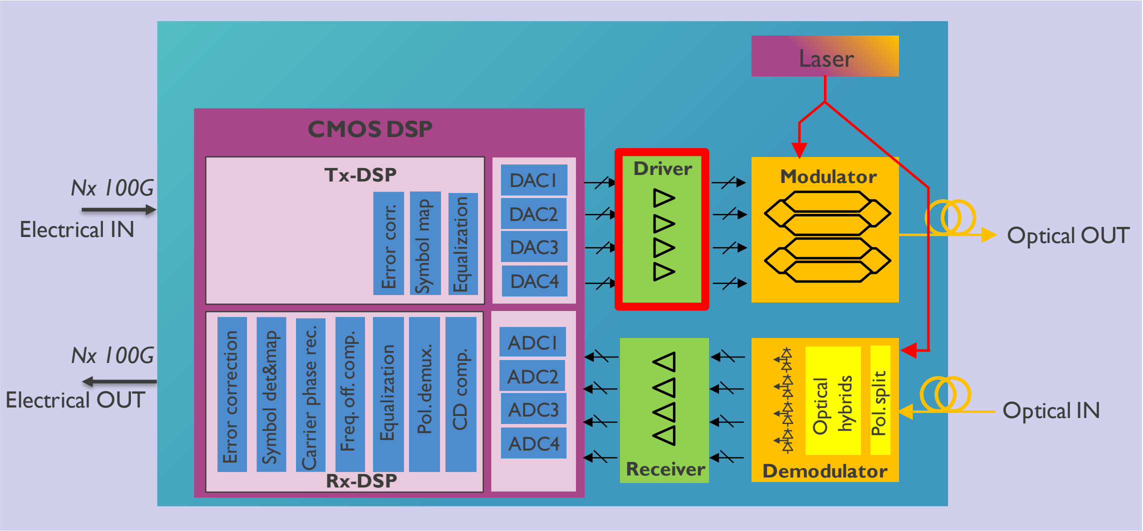


Drive voltage: 2Vpp

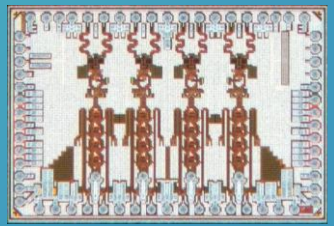
S.A. Srinivasan et.al., "60Gb/s waveguide-coupled O-band GeSi quantum-confined stark effect electro-absorption modulator", OFC'2021, paper Tu1D.3

Electronic front-ends for 100Gbaud operation and beyond

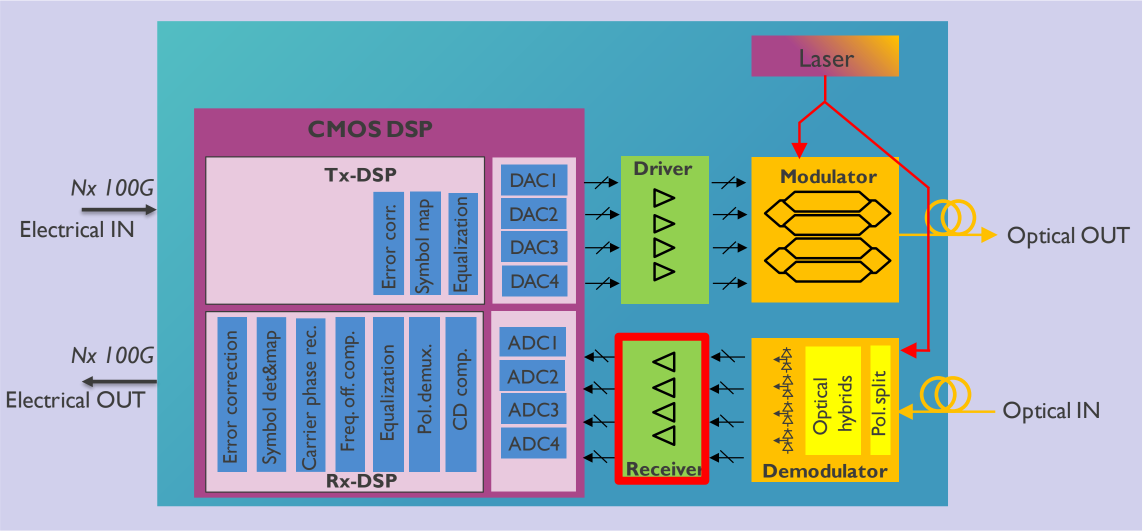
SiGe BiCMOS front-end electronics



- **4-ch. linear Mach-Zehnder modulator driver**
- STM 55nm SiGe BiCMOS
- ~90GHz bandwidth, 2.5Vpp swing
- Linear response, Traveling wave based



SiGe BiCMOS front-end electronics



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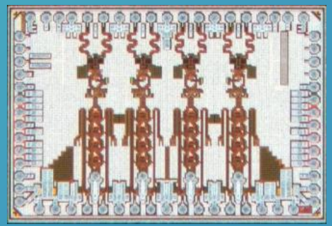
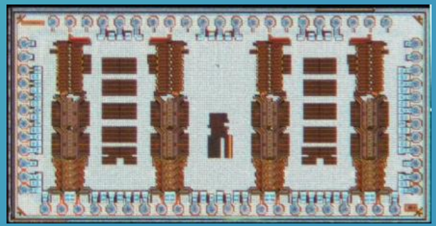
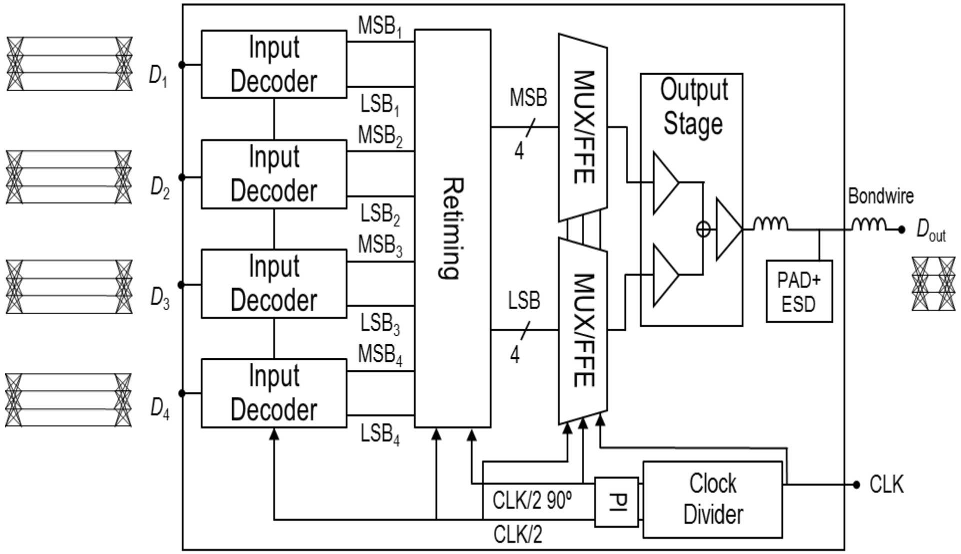


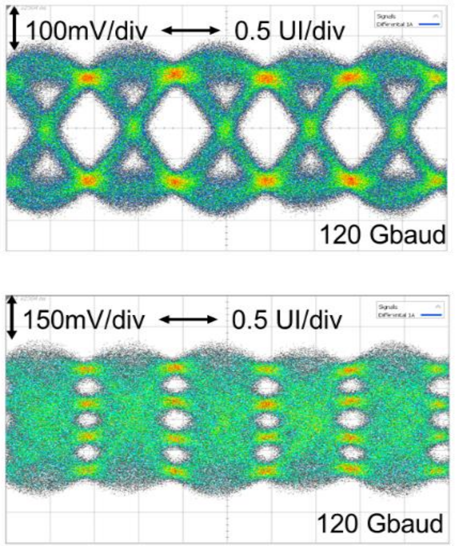
- **4-ch. linear transimpedance amplifier array**
- STM 55nm SiGe BiCMOS
- ~60GHz bandwidth
- Linear response, trav. wave based

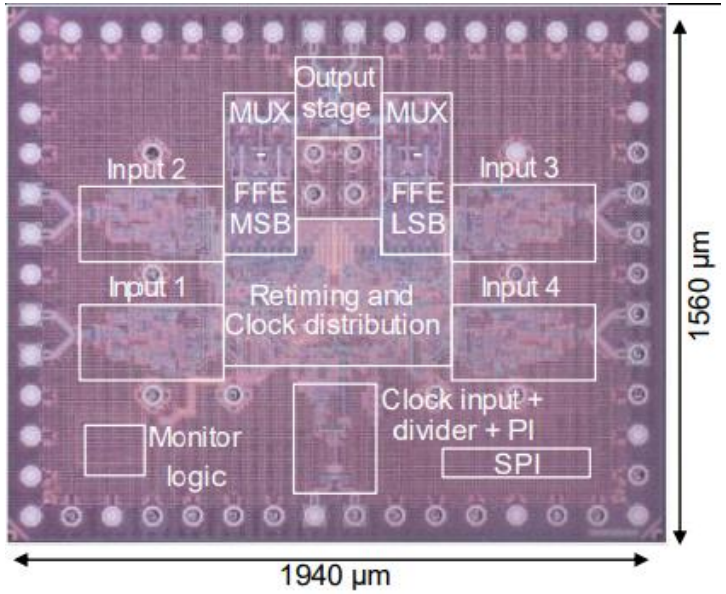


Ultra high-speed signal generation

120Gbaud capable multiplexer / equalizer







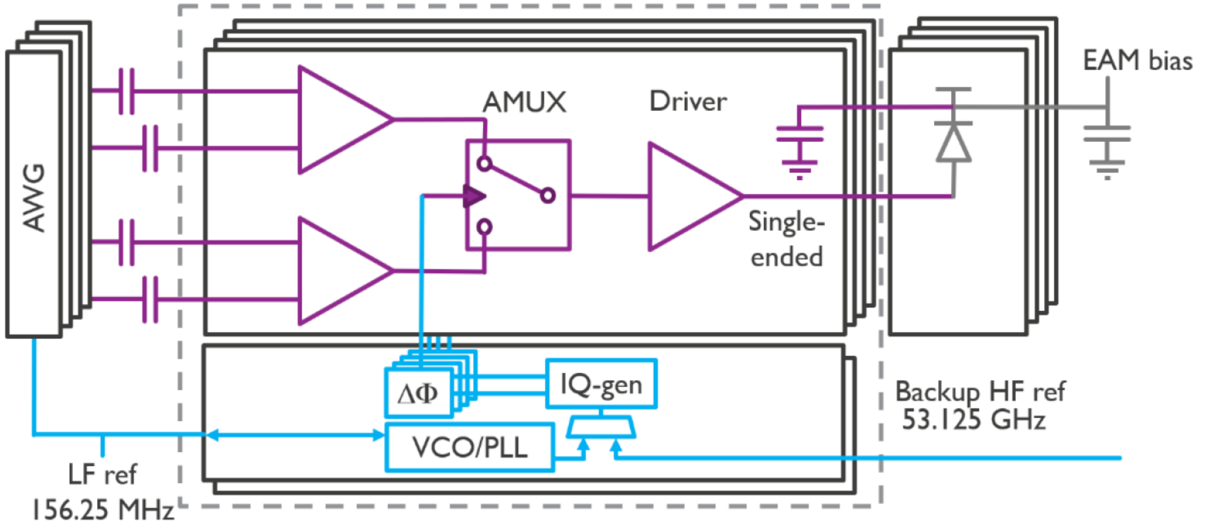
120Gbaud capable 4:1 multiplexer and equalizer

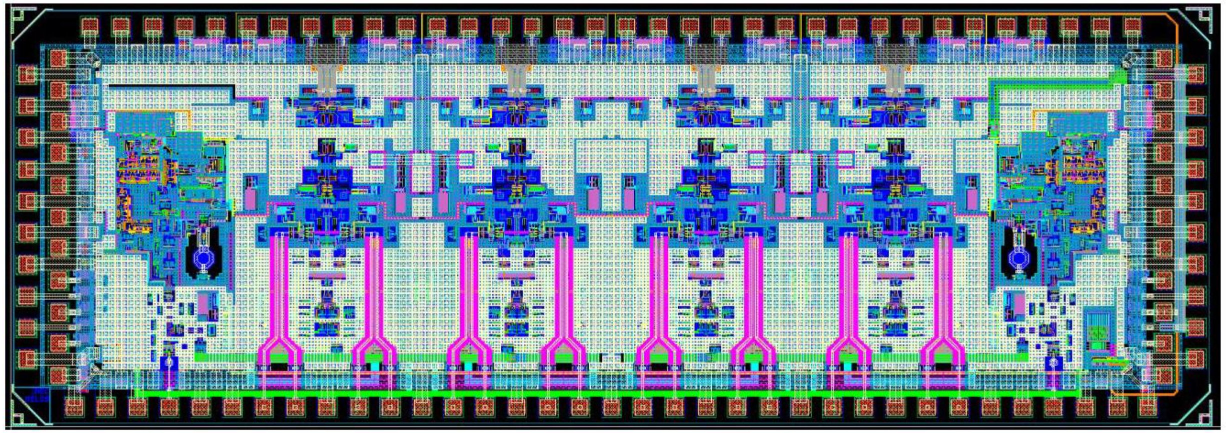
- Symbol-spaced, 7-tap equalizer
- Analog bandwidth >80GHz bandwidth, >1Vpp drive
- Power consumption including input decoding of 4x quarter-rate input channels: 2W

M. Verplaetse, H. Ramon, N. Singh, B. Moeneclaey, P. Ossieur and G. Torfs, "A 4-to-1 120Gb/s PAM-4 MUX with a 7-tap mixed-signal FFE in 55nm BiCMOS", *Custom Integrated Circuits Conference* (CICC 2021), April 2021.

Ultra high-speed signal generation

Quad channel 106Gbaud 2:1 multiplexer with modulator driver and clock generator



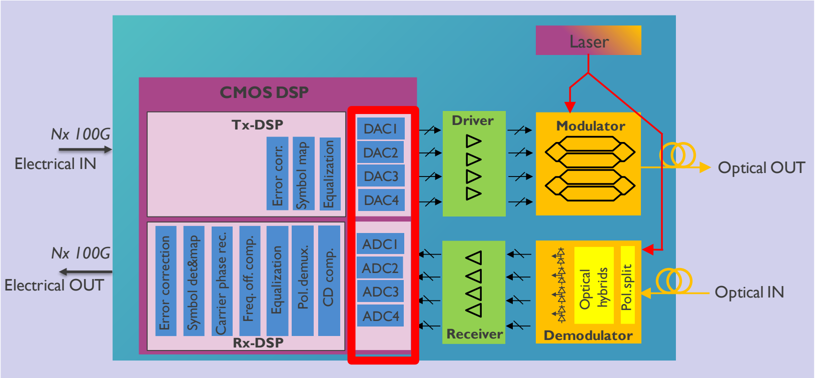


Input-side, each channel: two 53Gbaud PAM-4 input signals (for example)

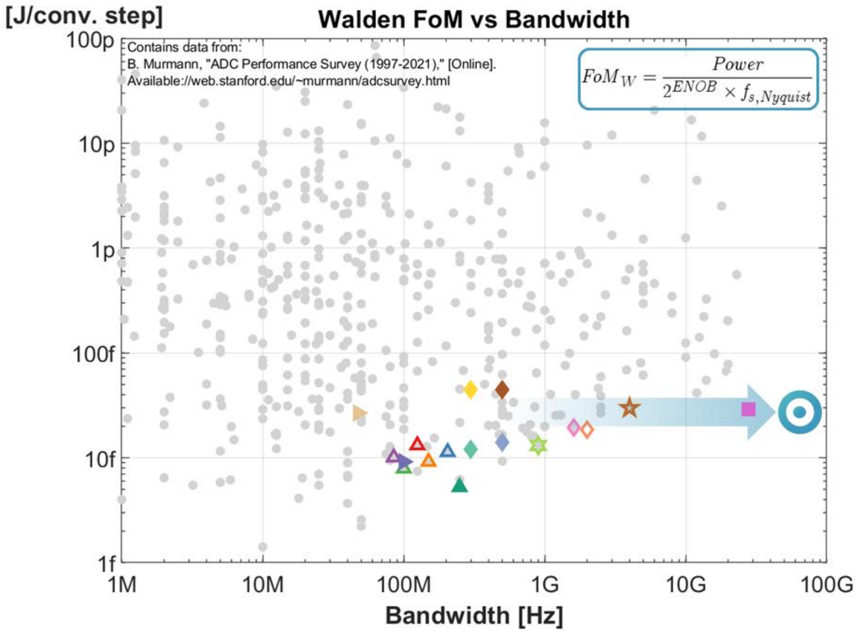
Function: linear interleaving, amplification using modulator driver (single-ended EAM driver in this case)

Output-side, each channel: one 106Gbaud PAM-4 output signal (for example)

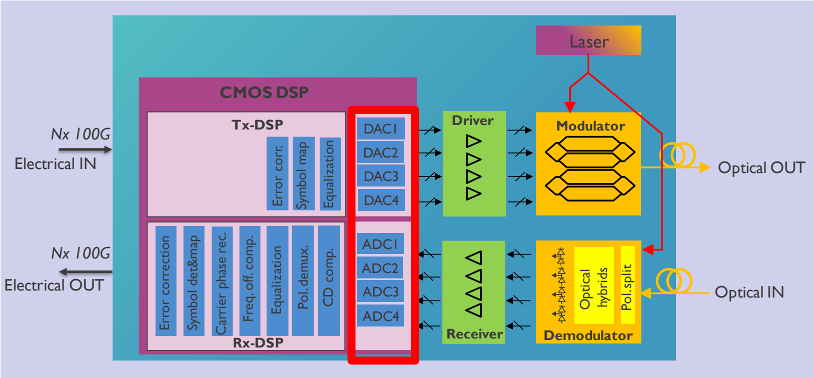
Ultra high-speed ADCs and DACs



- Conventional approaches such as time-interleaved SAR-ADC running into limitations
- Research focussed on breaking through these limitations



Ultra high-speed ADCs and DACs



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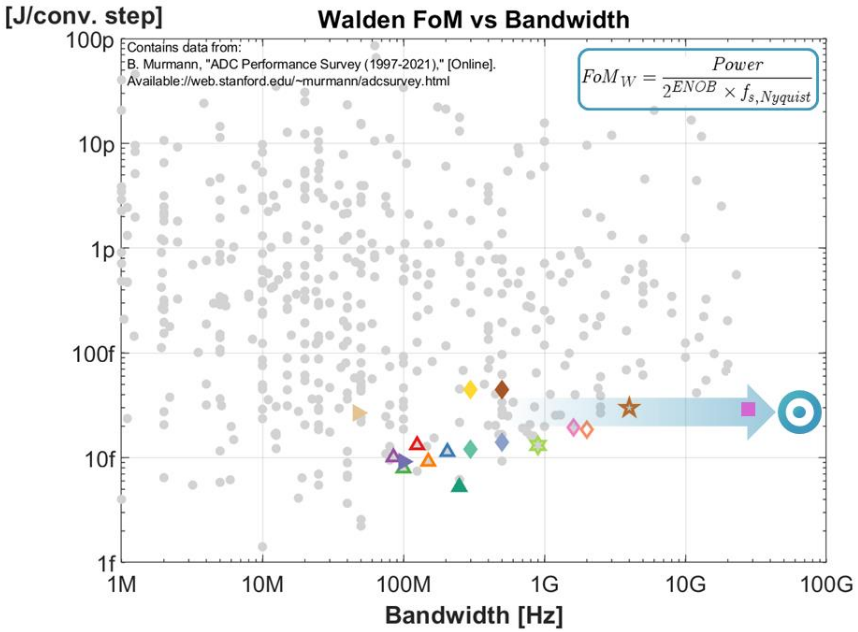

Specification	ADC Research Targets
Technology	5nm CMOS
Sampling rate [GS/s]	> 150
3dB bandwidth [GHz]	> 60
Resolution	7
Full scale ENOB	5 ... 6
Power [mW]	Targeting record efficiency

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Sampling rate [GS/s]	> 150
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Conclusion

- Next-generation optical transceivers to support Terabit/s capacities
  - Energy efficiency: pJ/bit
  - Density: Gb/s/mm or Gb/s/mm2
  - Low-cost: $/bit

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  - Energy efficiency: pJ/bit
  - Density: Gb/s/mm or Gb/s/mm2
  - Low-cost: $/bit
- Solutions according to trade-offs
  - Ultra high baudrate:
    - Integration of novel materials onto photonics platforms to achieve modulation and detection bandwidths
    - Advanced packaging, co-development with electronics critical
  - Optical IO
    - Ultra high integration density and low power

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