Optical interface

Electrical Engineering

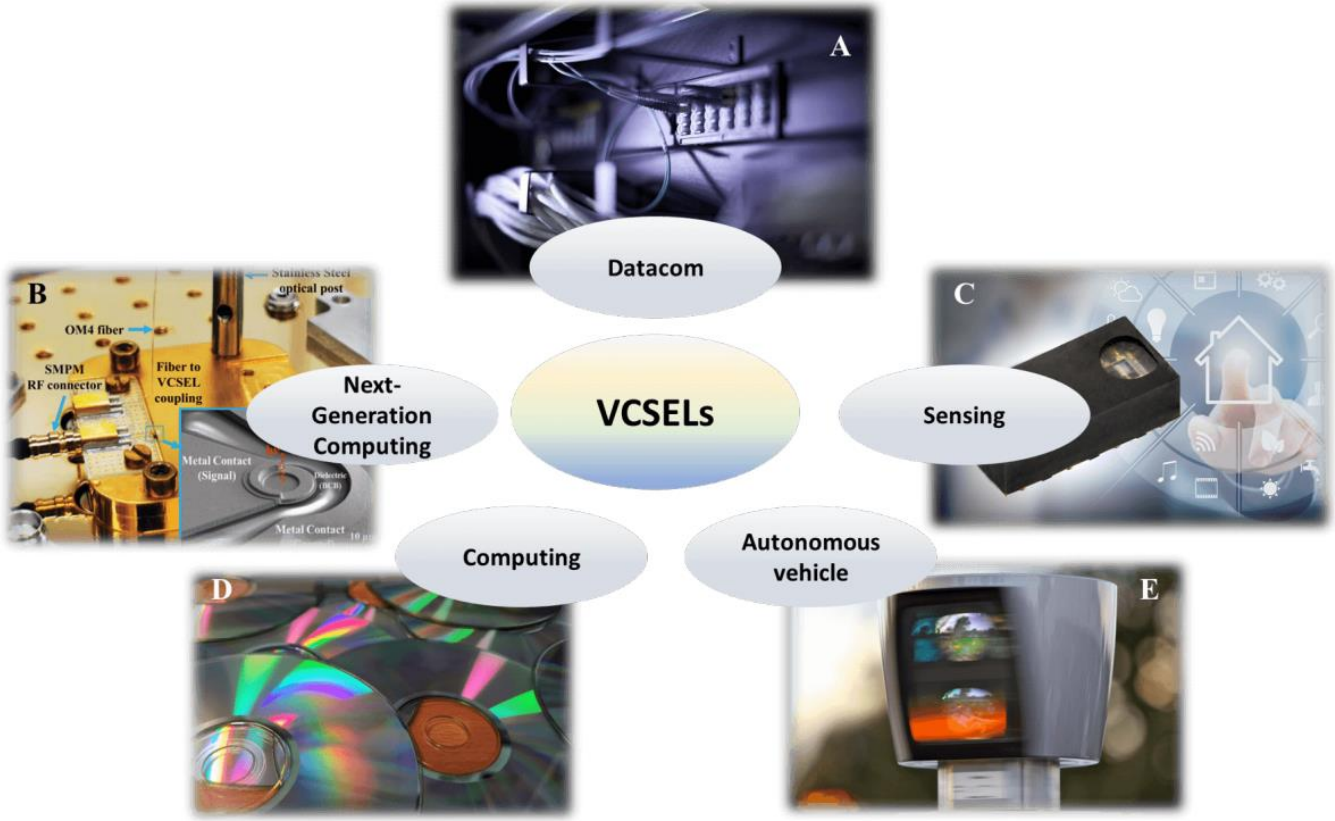
111061580

張睿紘

Outline

- Introduction & Background
- Wireline Communication Technology
- Characteristics of Modern High-Speed VCSELs
- VCSEL Transmitter Architecture
- Industry Analysis
- Conclusion
- References

Introduction



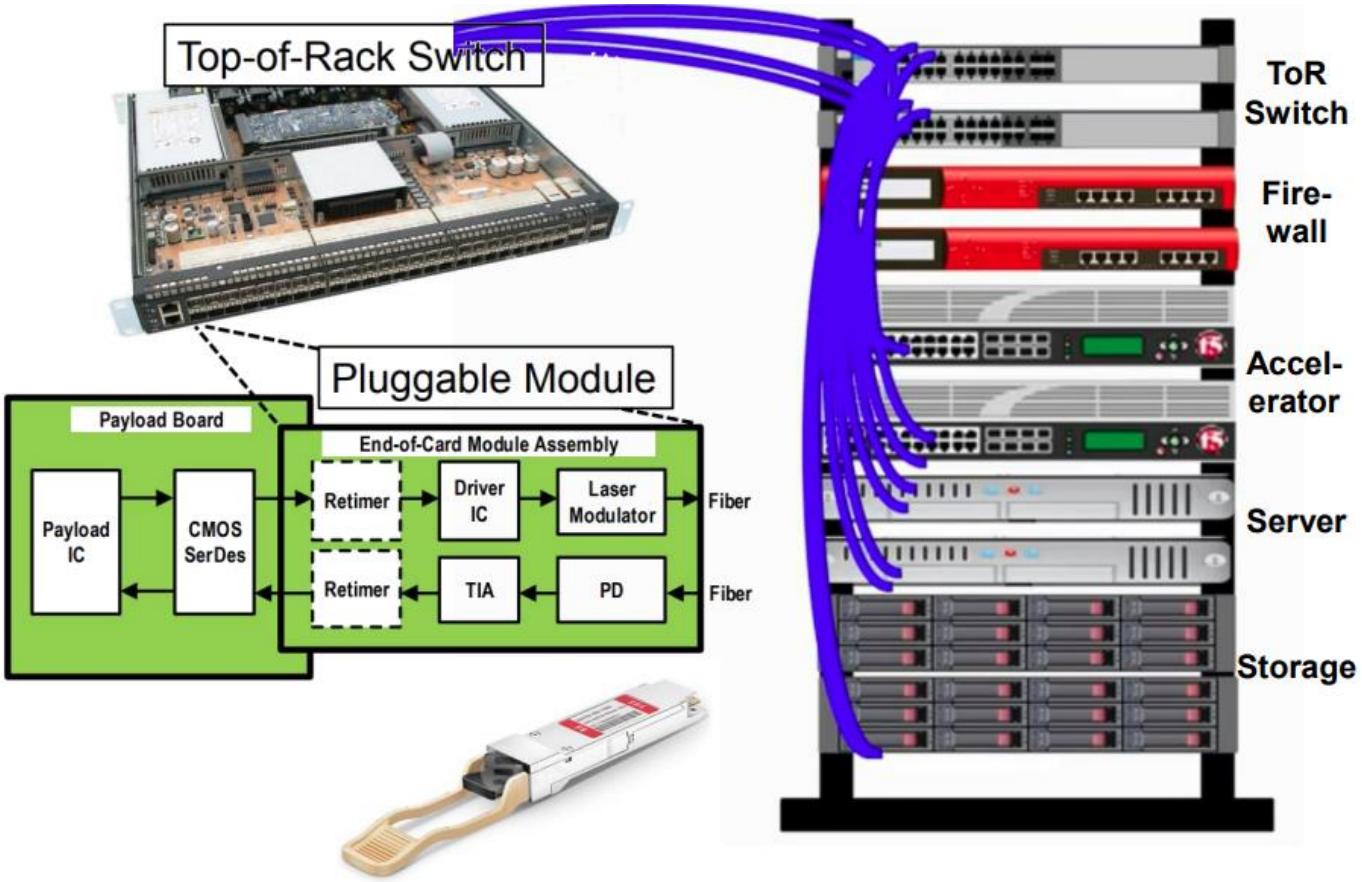
Background

Source: Cisco Global Cloud Index 2016-2021

- Data center traffic increases ~25% per year
- Over 70% traffic remains within data center
- To increase its power efficiency is important

Background

- Top-of-Rack (ToR) Switch in the Data Center



Background

IEEE P802.3bs™/D3.0						
Optical 400Gb/s						
Item	Name	Count	Ch.	Distance	Speed	Mod.
1	400GBASE-SR16	16	MM	0.5-100m	26.5625GBd	NRZ
2	400GBASE-DR16	4	SM	2m to 500m	53.125GBd	PAM4
3	400GBASE-FR16	8	SM	2m to 2km	26.5625GBd	PAM4
4	400GBASE-LR16	8	SM	2m to 2km	26.5625GBd	PAM4
Optical 200Gb/s						
Item	Name	Count	Ch.	Distance	Speed	Mod.
1	200GBASE-DR16	4	SM	2m to 500m	26.5625GBd	PAM4
2	200GBASE-FR16	4	SM	2m to 2km	26.5625GBd	PAM4
3	200GBASE-LR16	4	SM	2m to 2km	26.5625GBd	PAM4

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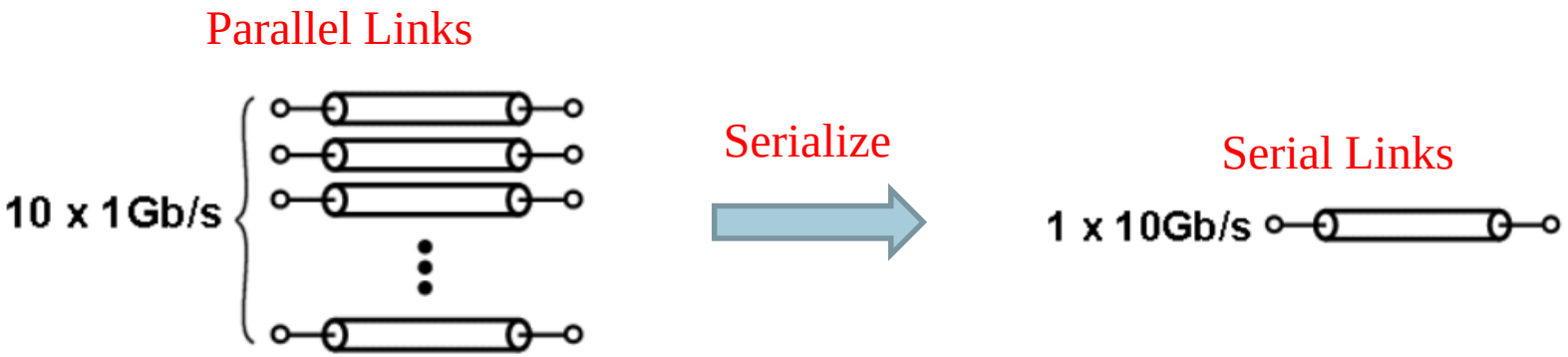
Wireline Communication Technology

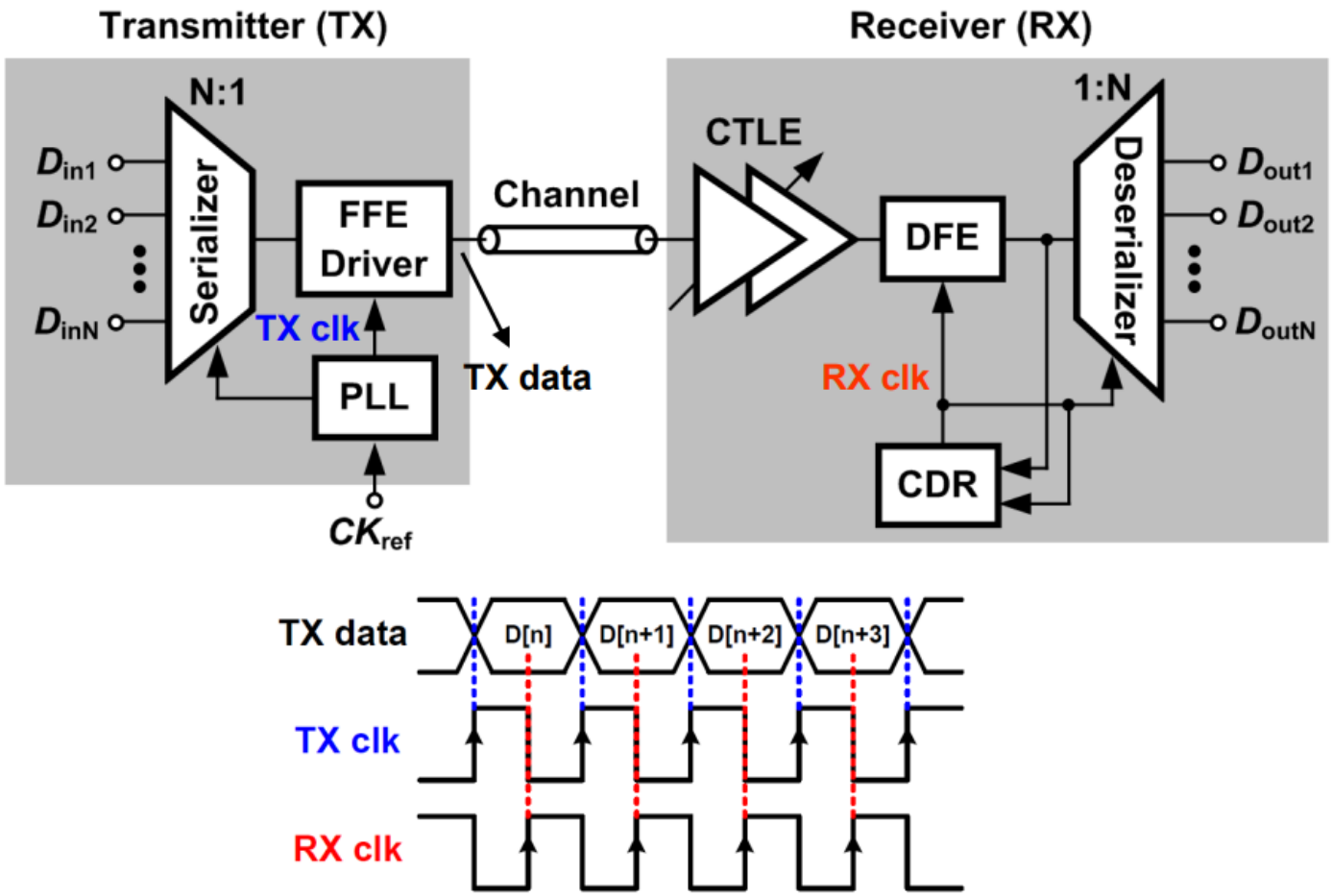
- Transmitter (TX): Transmit the signal through “channel”
- Channel: Impair the transmitted signal
  - Wireline: Coaxial, Fiber, Backplane trace, etc.
  - Wireless: Free-space, Multi-path reflection, etc.
- Receiver (RX): Recover the distorted data

Wireline Communication Technology



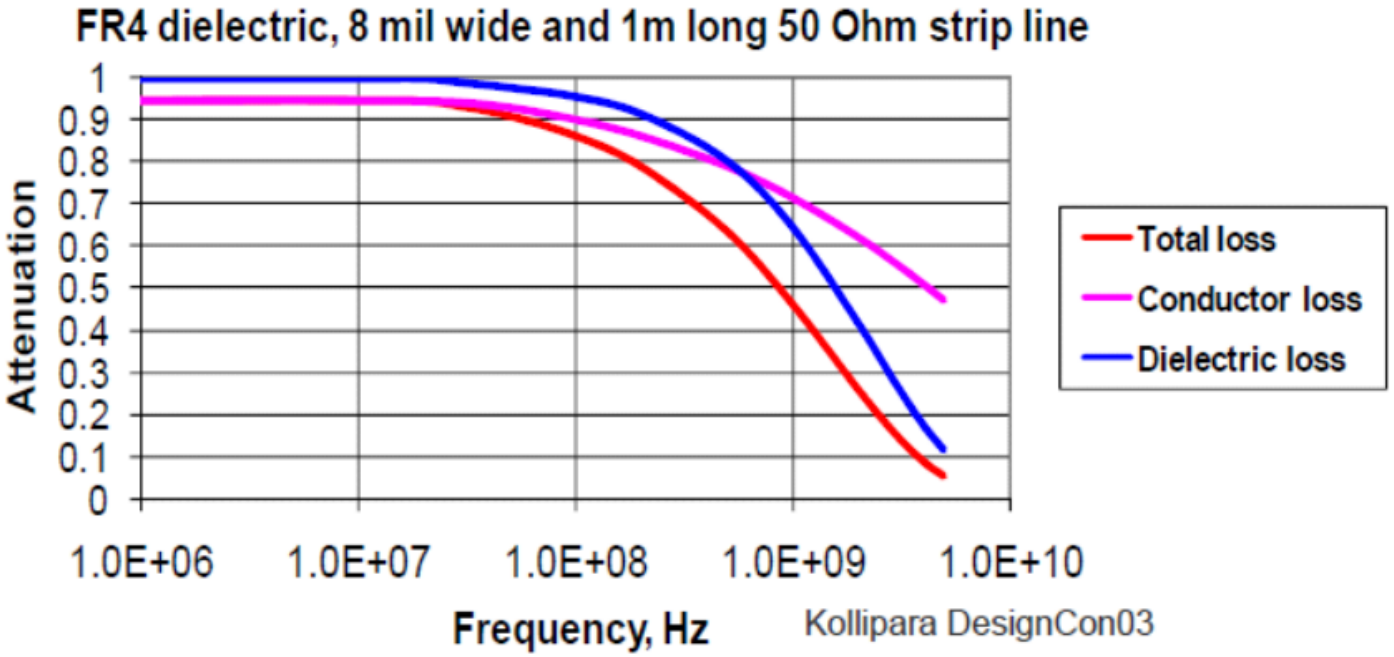
- Channel is expensive
- Reduce the area of the interconnections
- Synchronization for parallel links is difficult
- ➢ Cost of higher channel loss (increased bandwidth) and complicated circuit design

Wireline Communication Technology



Wireline Communication Technology

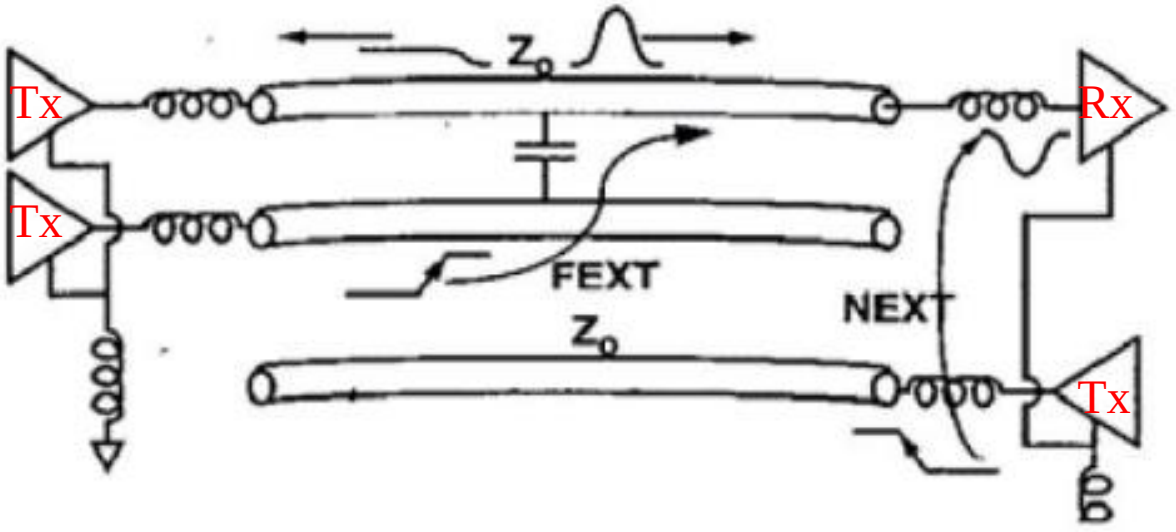
- Why optical channel?



- Skin Effect Loss $\propto \sqrt{F}$
- Dielectric Loss $\propto F$

Wireline Communication Technology

- Why optical channel?



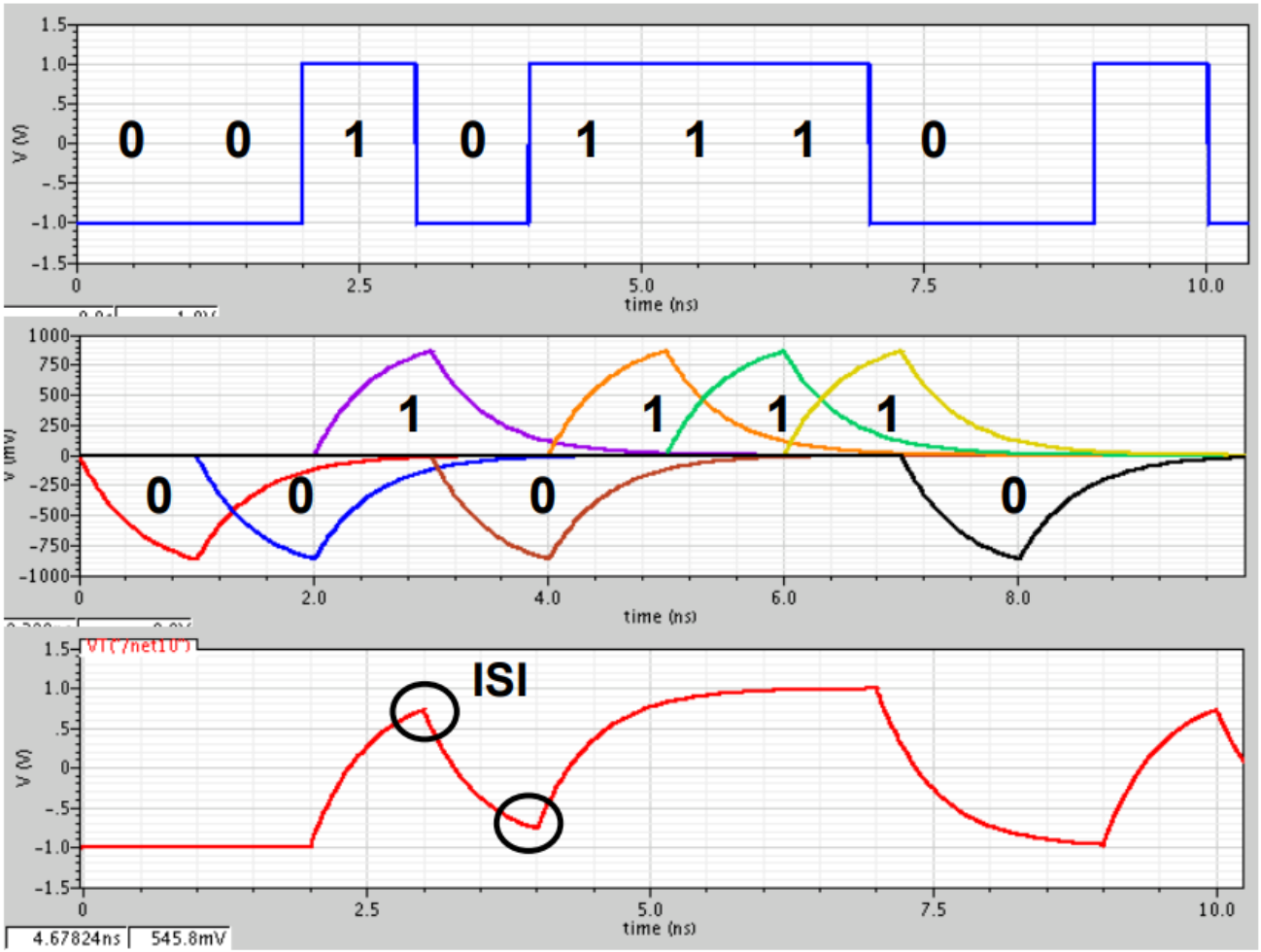
- "Near-end" xtalk: NEXT (reverse wave)
- "Far-end" xtalk: FEXT (forward wave)

Wireline Communication Technology

Digital Data

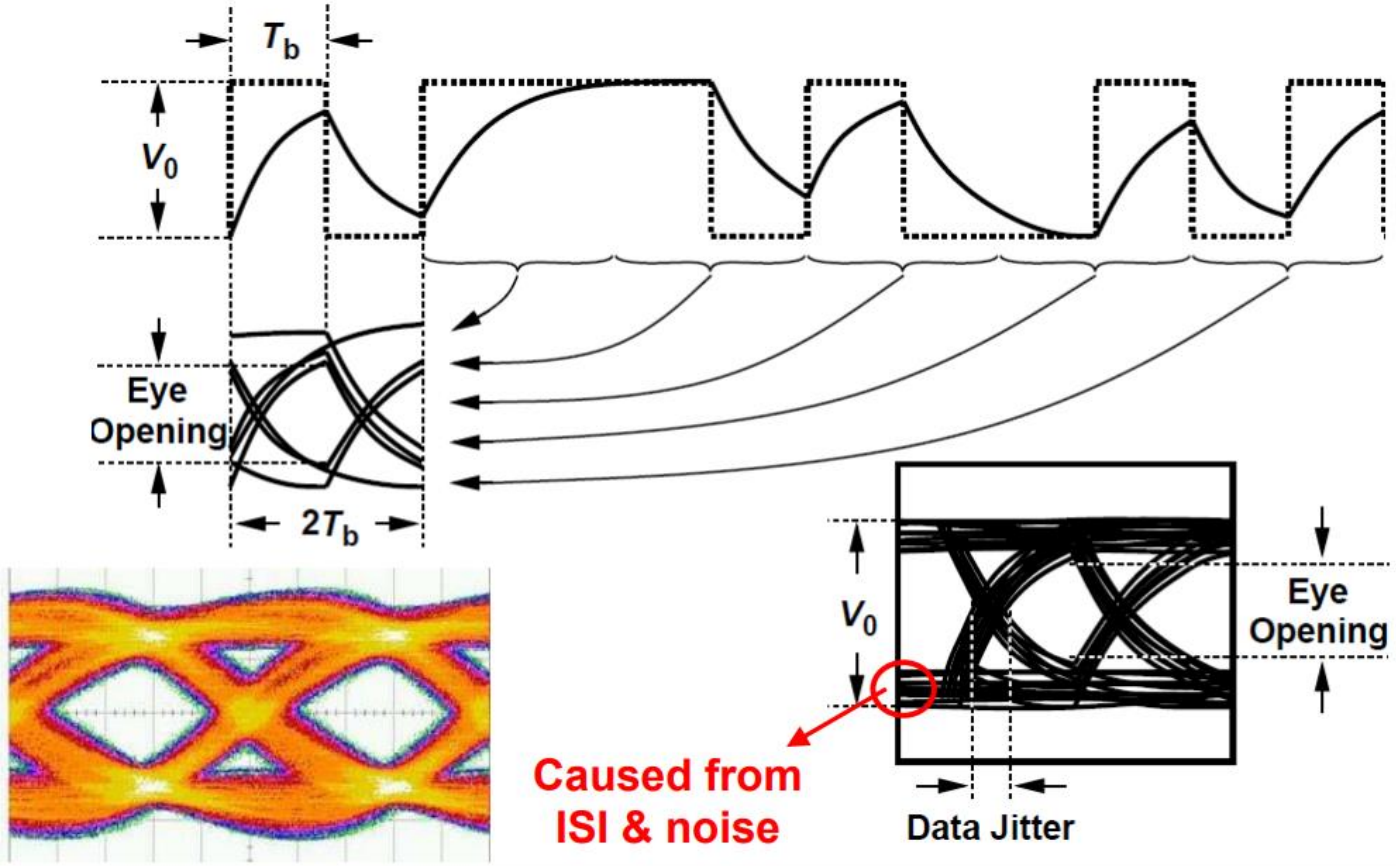
Pulse Response

Vo(t)



Wireline Communication Technology

- Eye diagram



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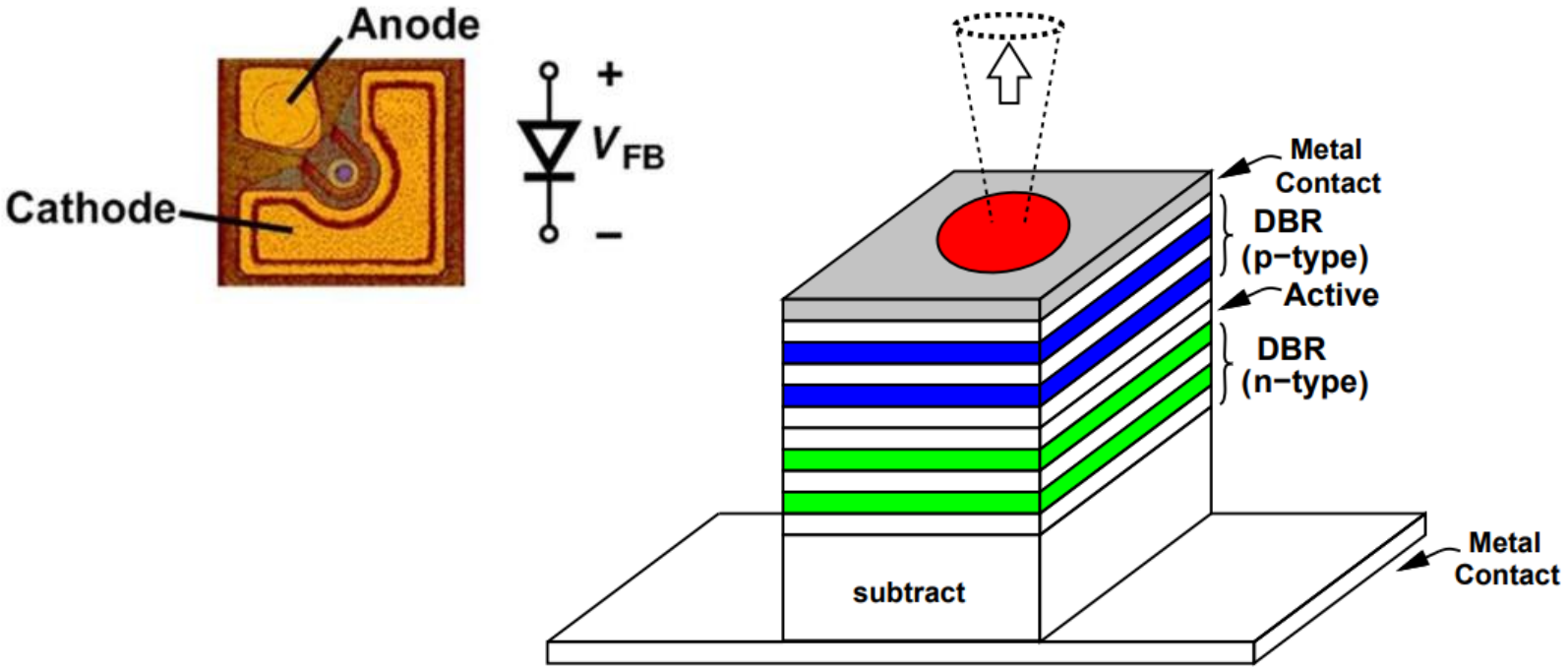
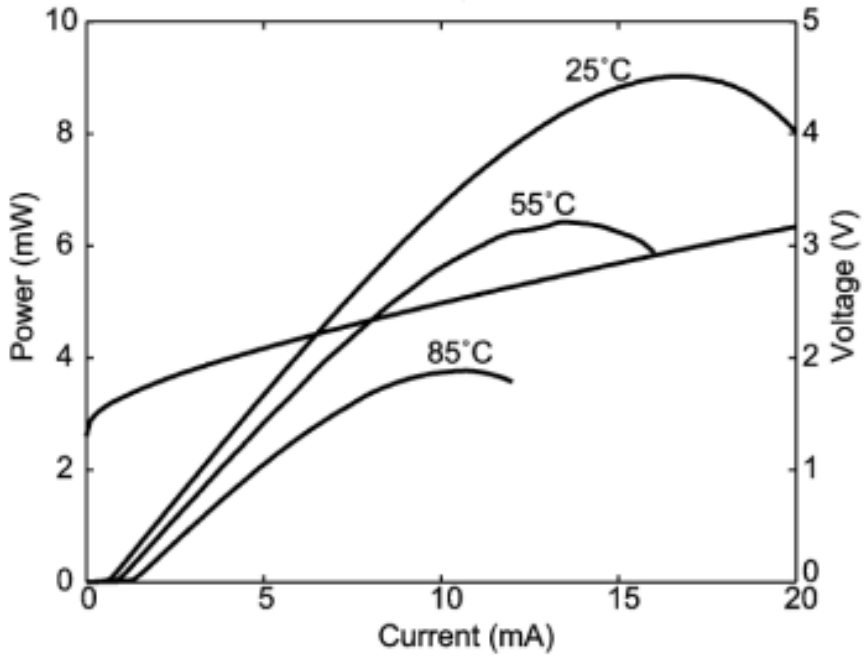
High-Speed VCSELs



High-Speed VCSELs

- DC response



V-I : voltage drop in different modulation current

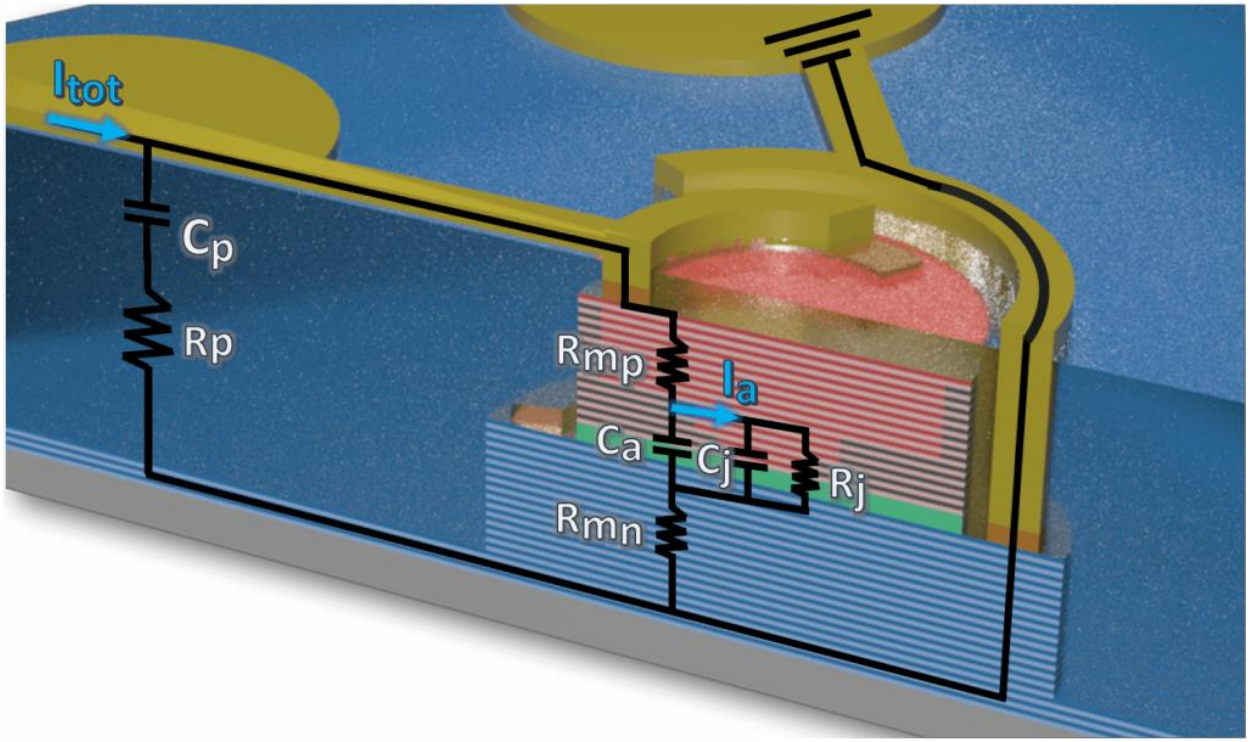
P-I：

$$P_{out} = \eta \times (\mathrm{I_{VCSEL}} - I_{TH})$$

High-Speed VCSELs

- AC response

$$H(f) = H_{\text{intrinsic}}(f) \cdot H_{\text{electric}}(f)$$



High-Speed VCSELs

- AC response

Electron density N, photon density Np, laser cavity volume V

Rate equations:

$$\frac{dN}{dt} = \frac{I_{VCSEL}}{qV} - \frac{N}{\tau_{sp}} - GNN_p \qquad \text{and}$$

$$\frac{dN_p}{dt} = GNN_p + \beta_{sp}\frac{N}{\tau_{sp}} - \frac{N_p}{\tau_p}.$$

High-Speed VCSELs

- AC response

Output optical power Po:

$$P_o = N_p h\nu V v_g \, .$$

$$\frac{P_o(s)}{I_{VCSEL}(s)} = \frac{h\nu v_g \alpha_m}{q} \times \frac{GN_p}{s^2 + s\left(GN_p + \frac{1}{\tau_{sp}}\right) + \frac{GN_p}{\tau_p}} .$$

$$\mathrm{H}(f) = const \times \frac{f_r^2}{f_r^2 + j\left(\frac{f}{2\pi}\right)\gamma - f^2} .$$

High-Speed VCSELs

- AC response

Resonance frequency:

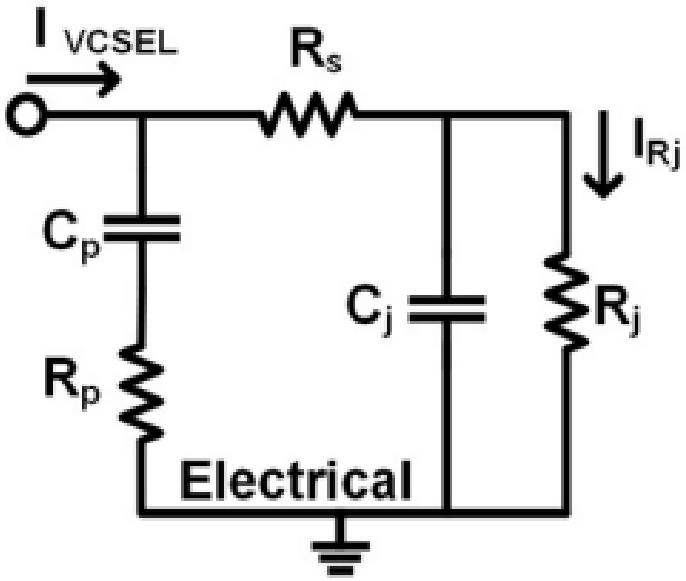
$$f_r = \frac{1}{2\pi}\sqrt{\frac{GN_p}{\tau_p}}\ .$$

$$f_r = D\sqrt{I_{VCSEL} - I_{TH}}\ .$$

$$\gamma = Kf_r^2 + \gamma_0\ .$$

High-Speed VCSELs

- Mayank Raj, JSSC ’16



Parameter	Value
Junction Capacitance (C_j)	110-117fF
Junction Resistance (R_j)	180-150Ω
DBR Resistance (R_s)	50Ω
Pad Capacitance (C_p)	10fF
Pad Resistance (R_p)	1Ω

High-Speed VCSELs

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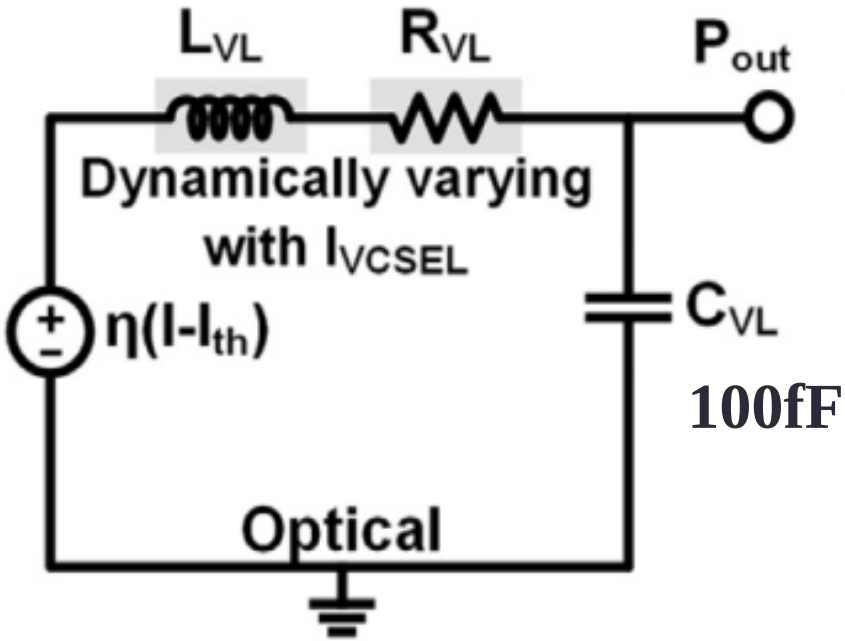
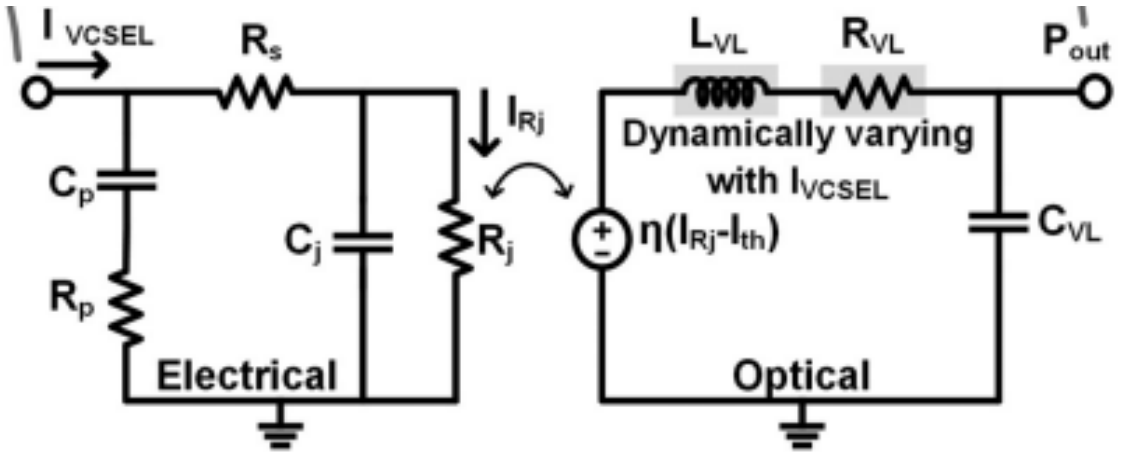


$$\frac{P_{out}(f)}{\eta(I-I_{TH})(f)} = \frac{1}{1-4\pi^2 L_{VL} C_{VL} f^2 + j\cdot 2\pi R_{VL} C_{VL} f}$$

$$L_{VL} = \frac{1}{4\pi^2 C_{VL} D^2 (I-I_{TH})} \text{ and}$$

$$R_{VL} = (K f_r^2 + \gamma_0) \times L_{VL} .$$

High-Speed VCSELs



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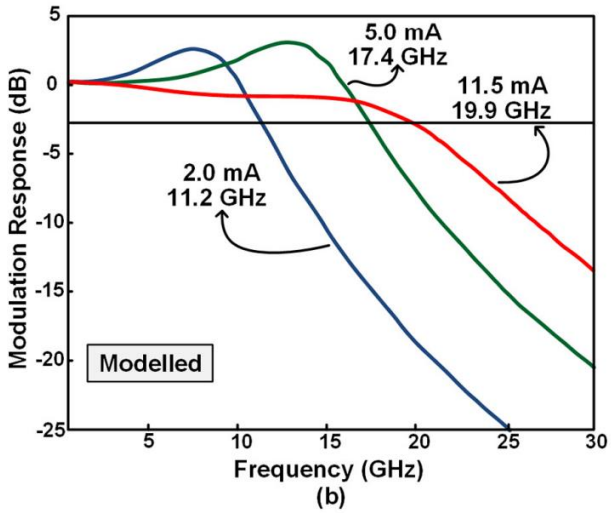

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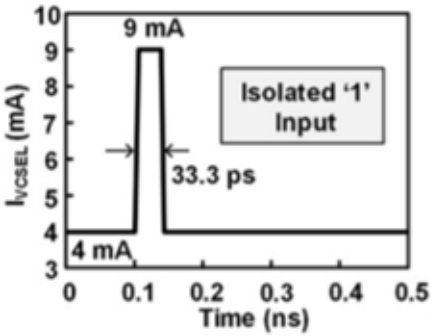

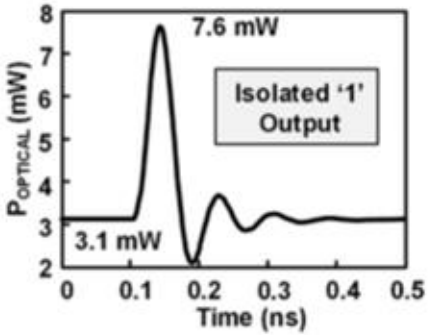

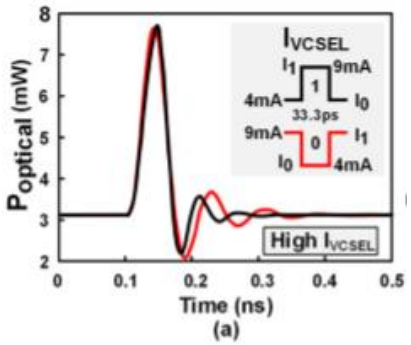

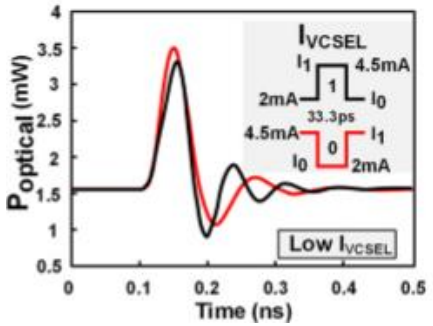

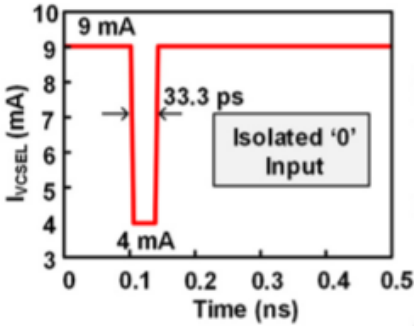

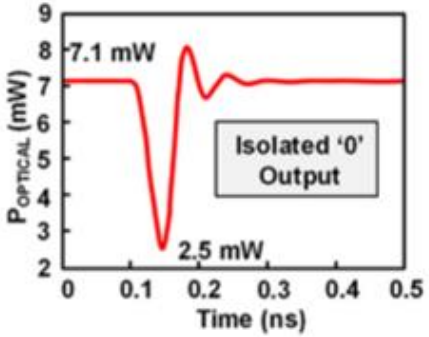

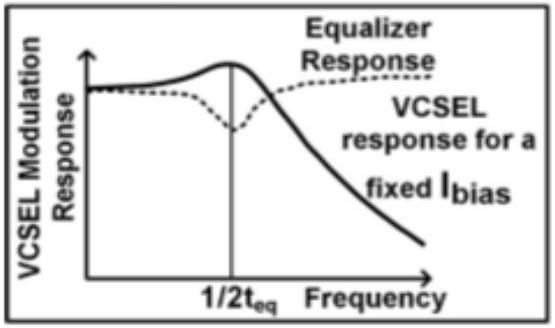

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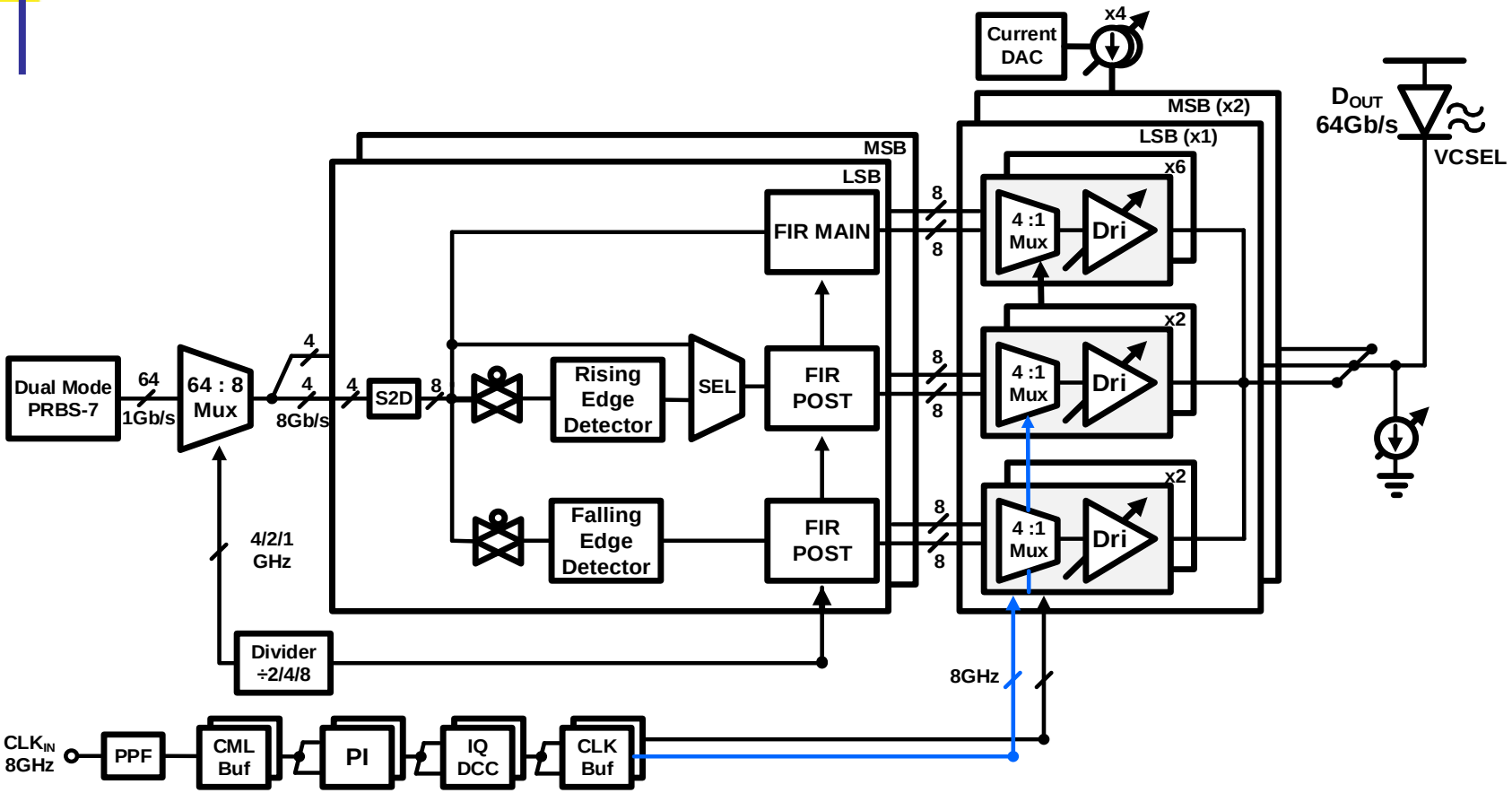
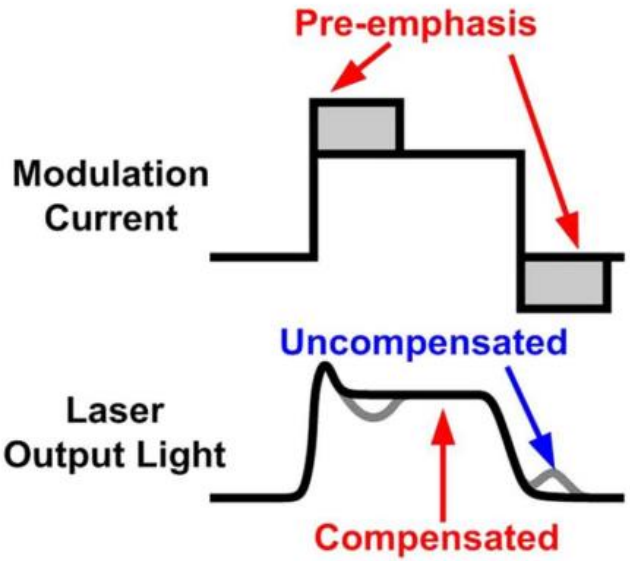
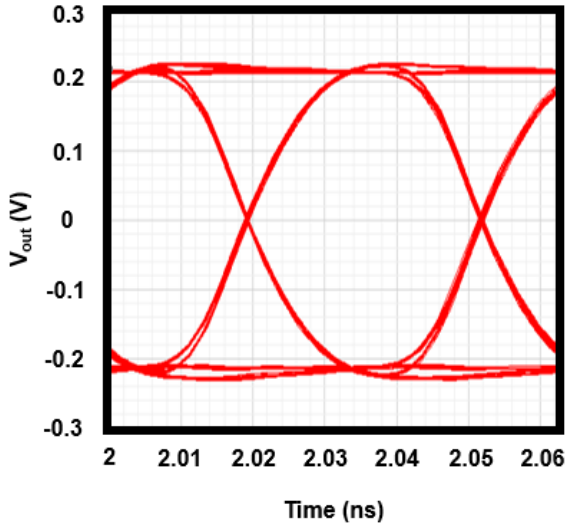


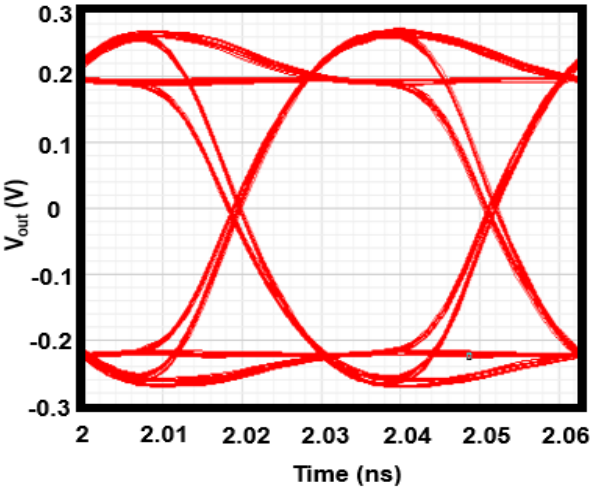
VCSEL Transmitter Architecture

- Tx electrical output





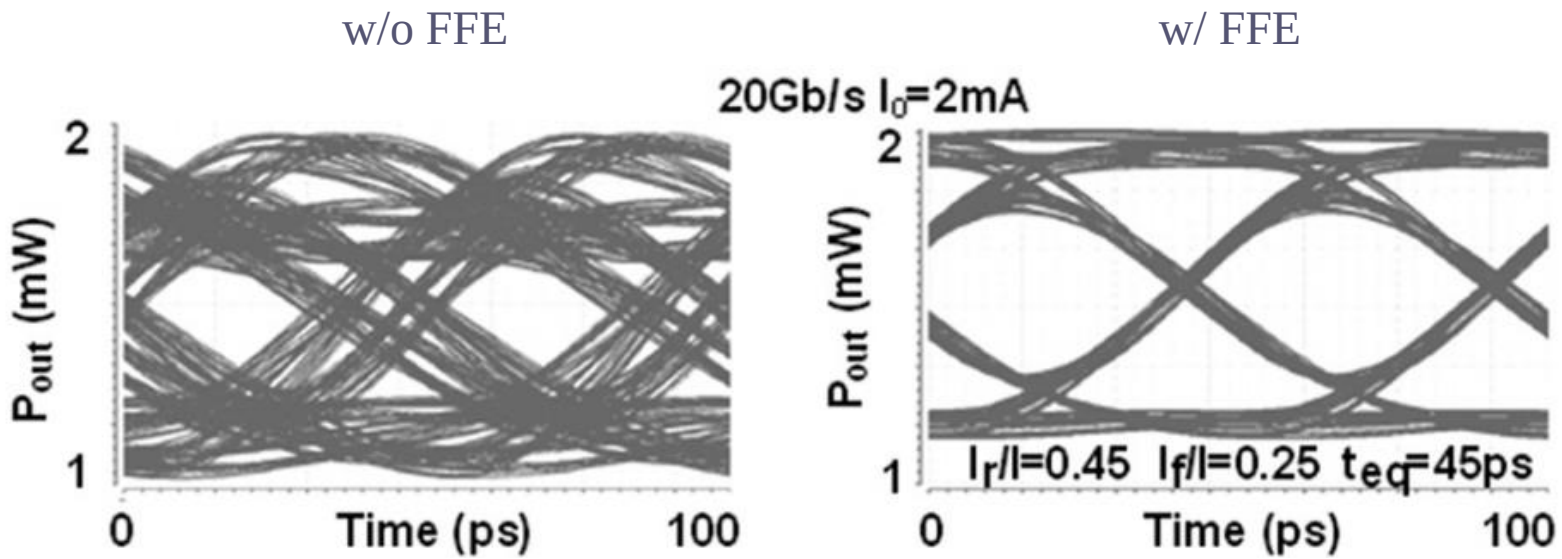
w/o FFE



w/ FFE

VCSEL Transmitter Architecture

- VCSEL optical output



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Industry Analysis

- Porter's five forces analysis

Bargaining power of customers

- High switching cost
- High product differentiation
- ➢ Low bargaining power of customers

Bargaining power of suppliers

- High bargaining power for optical component and foundry suppliers
- Low bargaining power for PCB suppliers

Competitive rivalry

- High market concentration
- High product differentiation
- ➢ High competitive rivalry

Threat of substitutes

- No substitute
- ➢ Market still has room to go

Threat of new entrants

- High entry costs
- Large market growth
- ➢ Still has the threat of new entrants

Industry Analysis

Strengths
- Low cost of processing
- Low power consumption in Tx and Rx circuit
- Less signal degradation

Weakness
- Low power output of VCSELs
- Limited distance
- Nonlinearity

Opportunities
- Achieving high modulation bandwidth at small current
- Increase optical output power

Threats
- New interconnection technology

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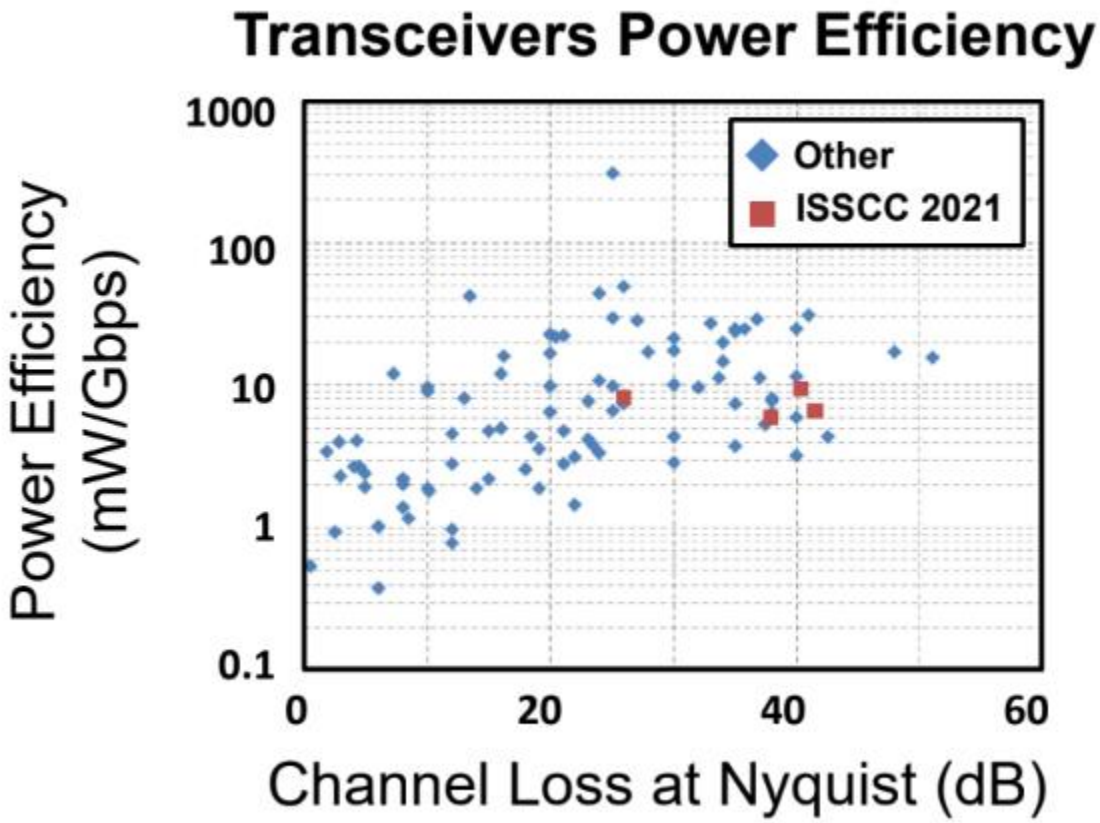

Source: ISSCC 2021 Wireline Trends

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References

- M. Ray el al., “A Modelling and Nonlinear Equalization Technique for a 20 Gb/s 0.77 pJ/b VCSEL Transmitter in 32 nm SOI CMOS”, May 05, 2016.
- Hao Tien Cheng el al., “Recent Advances in 850 nm VCSELs for High-Speed Interconnects” , Feb 13, 2022.
- Jri Lee, “Communication Integrated Circuits”
- Pen-Jui Peng, “Communication Electronics” lecture
- Po-Lin Lee, “A 64Gb/s 4-Level Pulse-Amplitude Modulation Current-mode VCSEL-based transmitter with 2-tap Dual-Mode Adjustable Nonlinear FFE in 40nm CMOS” , Jul , 2019.
- ISSCC 2022, SESSION 17, Advanced Wireline Links and Techniques

Thank you!