

Consideration on Modulation Formats of 400Gbps per Lane Optical Signal

Xiaojie Fan, Yu Xu, Ping Liao, Li Xu
Huawei Technologies

Contributor

Huijian Zhang

Lei Liu

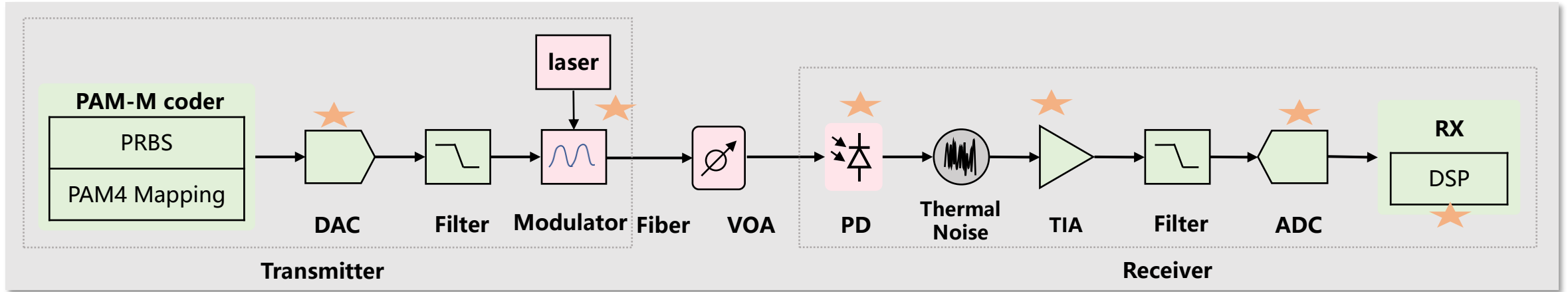
Zhoutian Liu

Introduction

- ◆ Driven by the AI wave, the era of 400Gbps per lane has arrived.
- ◆ As we know, at the OIF Q1 2026 meeting , the two projects—CEI-448G-VSR Common Electrical Chip-to-Module Interface Project and CEI-448G-LR Common Electrical Backplane Interface Project—were put forward and a basic consensus has been reached by [oif2026.075.00](#) and [oif2026.077.03](#).
- ◆ Meanwhile, at the IEEE March Plenary meeting, the study group—IEEE 802.3 400Gb/s/Lane Signaling Study Group—was formed based on [CFI_01_0326](#).
- ◆ Therefore, the curtain is about to rise on the standardization of 400Gbps per lane technology.
- ◆ The feasibility analysis of 400Gbps per lane optical side is crucial for the study group to dive into, especially for the feasibility of the modulation. The most important factor affecting this choice is the bandwidth of the channel and device.
- ◆ This proposal will focus on analyzing the technical feasibility of optical signal modulation formats for 400Gbps per lane.

Technical Feasibility Analysis (1/3)

- ◆ From an end-to-end point of view, the most critical parts that affect the technical feasibility of the optical side are modulator, drivers, PDs, TIAs, DAC/ADC and oDSP.



- ◆ The progress and potential of them at 400G/Lane is the key for evaluating the technical feasibility.
- ◆ So all the progress in the industry is analyzed in the following slides to provide further support for the technical feasibility decision to be made in the study group.

Technical Feasibility Analysis (2/3)

- ◆ There have been continuous reports recently of high-bandwidth optoelectronic devices such as drivers, modulators, PDs, TIAs, DAC/ADC and oDSP, whose bandwidths can support 400Gbps per lane PAM4 optical transmission.
- ◆ One modulator driver vendor has released products featuring over 110GHz of bandwidth drivers, capable of compensating for modulator bandwidth limitations like silicon MZM.
- ◆ Numerous vendors have demonstrated various high-bandwidth modulators, such as EML, TFLN and SiPh modulators, which have highly feasibility for 400Gbps per lane PAM4 transmission.

Modulator Drivers		
Part Number	A	B
type	Differential modulator Driver	Differential EML Driver
Max. Data-Rate(Gbaud)	260	224
Output Voltage(Vpp/Vppd)	2.5	2.0
Power Consumption(mW)	400	410
Applications	<ul style="list-style-type: none"> • 400Gbps/lane • 1.6T DR4 • 3.2T DR8 • 1.6T ZR/ZR+ • 1.6T Coherent LITE 	<ul style="list-style-type: none"> • 400Gbps/lane • 1.6T DR4 • 3.2T DR8
source		

High-Bandwidth Modulator			
	vendor	bandwidth	
InP(EML)	Company A	99GHz@6dB	source
	Company B	> 100GHz@3dB	source
	Company C	110GHz@3dB	source
TFLN	University A	110GHz@3dB	source
	Company D	110GHz@3dB	source
SiPh	Company B	70GHz@3dB	source
	Company F	> 70GHz@3dB	source

Technical Feasibility Analysis (3/3)

- ◆ Meanwhile, ongoing research on PDs and TIAs is also being continuously reported, offering hope for the end-to-end implementation of 400Gbps per lane PAM4 optical transmission.
- ◆ In addition, with process node advancements, DAC/ADC and oDSP chips supporting 400Gbps per lane PAM4 optical transmission have also been reported.
- ◆ Consequently, PAM4 emerges as a compelling and optimal choice for 400Gbps per lane optical transmission.

High-Bandwidth PD/TIA		
	Bandwidth	
PD	165GHz@3dB	source
TIA	130GHz@3dB	source
PD+TIA	>100GHz@3dB	source

Bandwidth Comparison— PAM4 vs PAM6

- ◆ Usually, the required analog bandwidth ranges from $0.45 * f_b$ to $0.55 * f_b$, where f_b is the baud rate.
- ◆ With continuous improvements in fabrication processes and device designs, the bandwidth of optoelectronic device is no longer a bottleneck—whether for PAM4 or PAM6 modulation of 448Gbps per lane optical transmission.
- ◆ For PAM4 modulation, the bandwidth of silicon photonic devices is slightly low, but bandwidth compensation via a modulator driver is available. Therefore, 448Gbps per lane PAM4 modulation is no longer constrained by bandwidth.

	Device	Required bandwidth	Current bandwidth	448Gbps PAM4 ($f_b=224\text{GBd}$)	448Gbps PAM6 ($f_b=174\text{GBd}$)	Remarks
TX	DAC	$0.45 * f_b \sim 0.55 * f_b$	> 100GHz	✓	✓	Source
	DRV		130GHz	✓	✓	Mentioned in the background
	EML		110GHz	✓	✓	
	TFLN		110GHz	✓	✓	
	SiPh		$\geq 70\text{GHz}$	Slightly low	✓	
PD+TIA	> 100GHz		✓	✓		
RX	ADC		> 100GHz	✓	✓	Source

Conclusion

- ◆ This proposal presents a comparative analysis of the technical feasibility for 400Gbps per lane optical signal from the bandwidth perspective:
 - Bandwidth—whether based on PAM4 or PAM6 modulation, the bandwidth of optoelectronic devices is no longer a bottleneck with the improvements in fabrication processes and device designs.
- ◆ Therefore, for 400Gbps per lane, the technical feasibility for the optical side is assured.

Thank You