

Short-Haul 56-Gbaud High-Speed Optical Device (SiPh, DML) Evaluation using AH15199B Wideband Linear Amplifier

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1. Introduction

In the growing optical communications market, 400 GbE is adopted widely as a leading high-capacity solution driven by expansion of AI/ML. To support even higher demands, the IEEE802.3 ETHERNET WORKING GROUP is developing standards for enhanced transmission capacity, targeting 100 Gbps and 200 Gbps per lane. The AH15199B wideband linear amplifiers are suitable for evaluating >100 Gbaud for 200 Gbps/lane as well as coherent modulation now being standardized for 200 GbE/400 GbE/800 GbE/1.6TbE. These amplifiers are also suitable for evaluating the performance of short-haul mainstream optical devices (SiPh/DML modulators) for 100 Gbps/lane (56 Gbaud) in data centers.

This application note focuses on evaluation of 56 Gbaud high-speed optical devices for short-haul applications. For evaluation of >100 Gbaud high-speed optical devices for medium- and long-haul applications, refer to the "High-Speed Optical Device (EML, LN-MZM) Evaluation using AH15199B Wideband Linear Amplifier" Application Note.

2. Interface

The IEEE 802.3dj 800 Gb/s, 1.6 Tb/s Ethernet Task Force is developing standards for 200 Gbps/lane with higher speeds (IMDD method) for mid-haul (500 m to 2 km). For long-haul (>10 km), standardization of coherent schemes has been started in IEEE 802.3dj and OIF, accelerating optical transmission systems beyond 1 Tb/s speeds. In such contexts, 100 Gbps/lane (IMDD method), which is standardized for short-haul (50 to 100 m) in data centers, requires compact and low-power-consumption by optical devices (SiPh/DML).

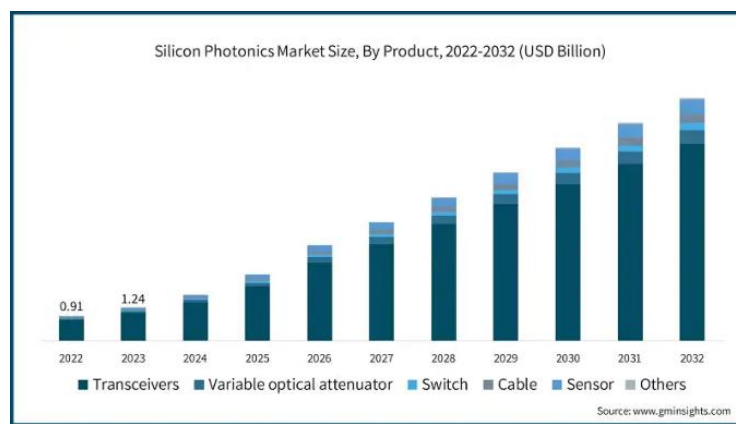
IEEE802.3/OIF Standard

Interface Ethernet Standard	Signaling Rate	MMF		SMF					
		50 m (VR)	100 m (SR)	500 m (DR)	2 km (FR)	10 km (LR)	20 km (ER)	40 km (ER)	80 km (ZR)
200G	100 Gb/s	200GBASE-VR2	200GBASE-SR2	200GBASE-DR1	200GBASE-FR1				
	200 Gb/s								
	Coherent								
400G	100 Gb/s	400GBASE-VR4	400GBASE-SR4	400GBASE-DR4	400GBASE-FR4				
	200 Gb/s								
	DP-16QAM 59.8 Gbaud								400ZR
800G	100 Gb/s	400GBASE-VR8	800GBASE-SR8	800GBASE-DR8	800GBASE-DR8-2	800GBASE-LR4			
	200Gb/s								
	DP-16QAM 118.2 Gbaud 123.6 Gbaud 123.6 Gbaud								
1.6T	100 Gb/s								
	200 Gb/s								
	16QAM 112 Gbaud								

3. Silicon Photonics (SiPh) Market

The global silicon photonics (SiPh) market size is estimated at US\$ 2.24 billion in 2023 and is projected to grow at a CAGR of 24.8% to US\$15.83 billion by 2032 from US\$2.69 billion in 2024.

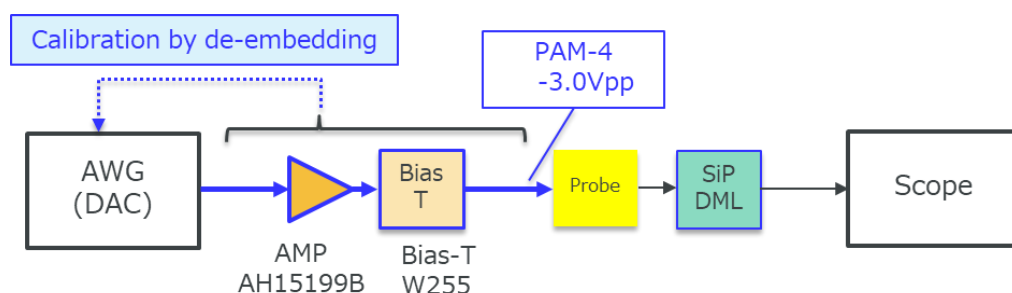
Integration of silicon substrates and optical devices is expected to enable faster, more reliable and cost-effective data transmission, resulting in smaller size and lower power consumption optical communication devices.



Source: GMI Silicon Photonics Market Global Forecast (2024-2032)

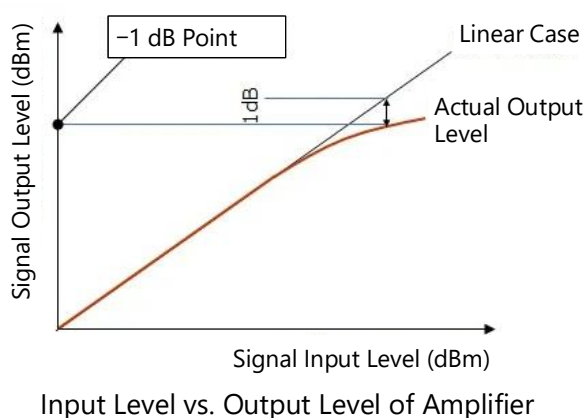
4. Optical Device Evaluation Setup

One issue when testing a device under test (DUT) is to verify the waveform quality of the signal source. Therefore, the impact of frequency characteristics (loss) of external devices, such as cables, on signal distortion must be corrected (calibrated) by the AWG's (DAC) de-embedding function.

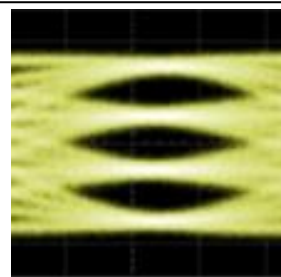


IMDD Optical Device (SiPh, DML) Evaluation Setup

To test short-haul optical devices (SiPh, DML) requiring small size and low-cost solutions, the signal source must have high output power and good waveform quality for the DUT target performance. For example, a SiPh/DML modulator used at 56 Gbaud may require a drive signal of up to 3.0 Vpp. The AH15199B wideband linear amplifier has a wide bandwidth of over 130 GHz at -6 dB and a P1dB characteristic of about 15 dBm. When configured as a signal source for 56 Gbaud PAM4 signals, it can output a high amplitude of up to 3.0 Vpp. It also achieves good waveform quality with a TDECQ of 0.84 dB and RLM of 0.947 (@ $V_{out} = 3.1$ Vpp), making it ideal as a reference signal source.



56 Gbaud PAM4 Waveform
 $V_{out} = 3.1$ Vpp



5. Optical Device Evaluation Items

5.1 Optical Modulation Amplitude (PAM4: Outer OMA)

Outer OMA measures the difference between two optical power levels generated by a laser source: for NRZ signals, the high level is "1" when the source is "on" and the low level is "0" when the source is "off". This parameter is useful for determining the effectiveness of signal modulation when the extinction ratio is not high. For PAM4 signals, the high level is "3" when the light source is "on".

5.2 TDECQ

TDECQ (Transmitter Dispersion and Eye Closure Quaternary) is the ratio of the amount of noise (noise margin) added to the DUT (transmitter) and to the ideal transmitter to achieve the target SER (Symbol Error Rate), expressed in dB. A DUT transmitter is better with lower TDECQ. Unlike the NRZ signal, the mask margin test is not suitable for optical transceivers with PAM4 modulation, because the difference between adjacent amplitude levels is very small. Therefore, TDECQ was standardized as the alternative to the usual mask margin test, as shown below.

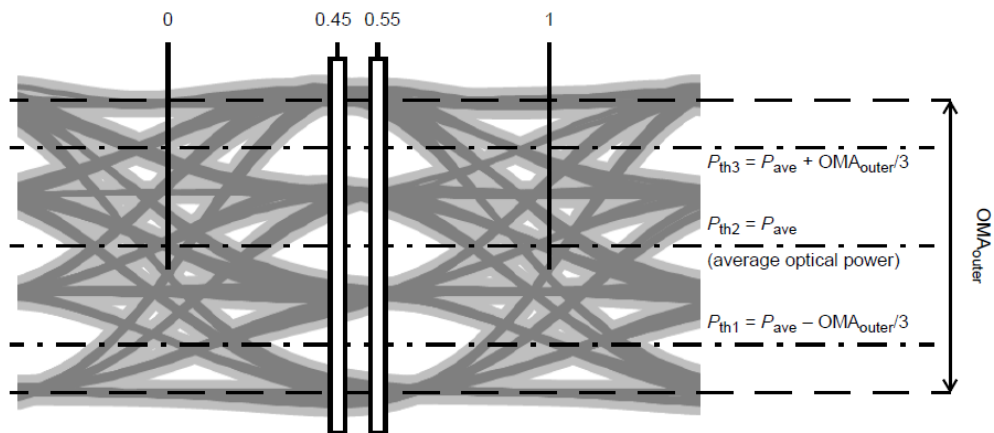


Illustration of TDECQ Measurement

Source: IEEE802.3-2022

$$R = \sqrt{\sigma_G^2 + \sigma_S^2}$$

$$TDECQ = 10\log_{10} \left(\frac{OMA_{outer}}{6} \times \frac{1}{Q_t R} \right)$$

R: RMS noise,

Qt: Consistent with BER and target SER for Gray coded PAM4 (= 3.414).

5.3 Linearity (R_{LM})

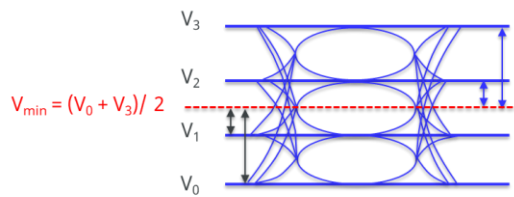
RLM (Ratio Level Mismatch) or the ratio between the eyes is another important parameter in evaluating the PAM signal. To help understand RLM evaluation, an example of a linearity evaluation comparison between a PAM4 signal with an ideal eye opening and a PAM4 signal with a nonlinear eye opening is shown below.

$$V_{min} = \frac{V_0 + V_3}{2}$$

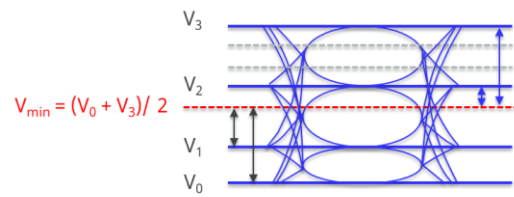
$$ES1 = \frac{V_1 - V_{min}}{V_0 - V_{min}}$$

$$ES2 = \frac{V_2 - V_{min}}{V_3 - V_{min}}$$

$$R_{LM} = \min((3 \times ES1), (3 \times ES2), (2 - 3 \times ES1), (2 - 3 \times ES2))$$



Ideal Eye
 $R_{LM} = \min((3 \times 1/3), (3 \times 1/3), (2 - 3 \times 1/3), (2 - 3 \times 1/3))$
 $= \min(1, 1, 1, 1)$
 $= 1$



Non-linear Eye Example
 $R_{LM} = \min((3 \times 2/3), (3 \times 1/4), (2 - 3 \times 1/2), (2 - 3 \times 1/4))$
 $= \min(2, 0.75, 0.5, 1.25)$
 $= 0.5$

Linearity (R_{LM}) Evaluation Example

6. Optical Device Evaluation

The IEEE802.3 standard specifies TDECQ tolerances for each Outer OMA condition (e.g. Fig. 124.-2a (400GBASE-DR4-2)), and requires confirmation under each condition.

Two 56 Gbaud PAM4 output waveforms (2.2 and 3.1 Vpp) using a wideband linear amplifier are shown below for reference.

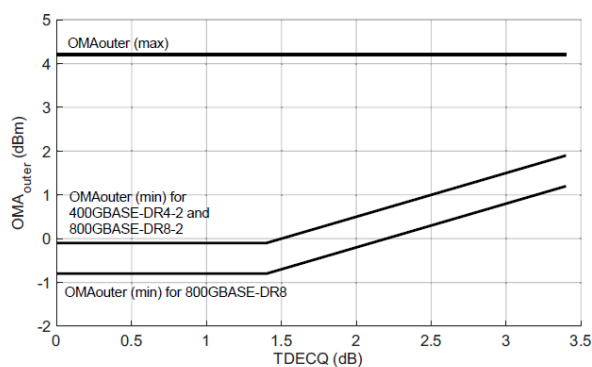
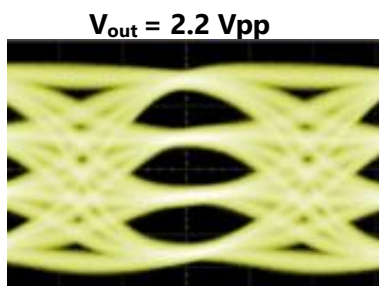
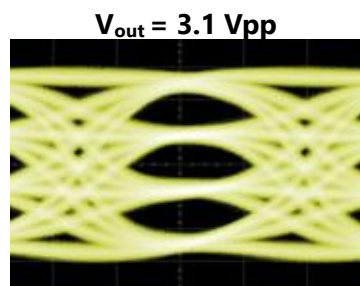


Figure 124-2a—OMA_{outer} (max) and OMA_{outer} (min) versus TDECQ for 400GBASE-DR4-2, 800GBASE-DR8, and 800GBASE-DR8-2

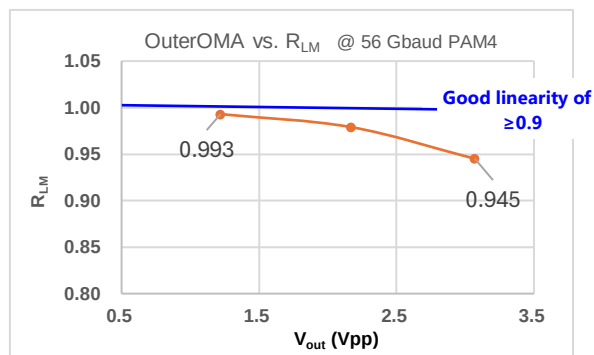
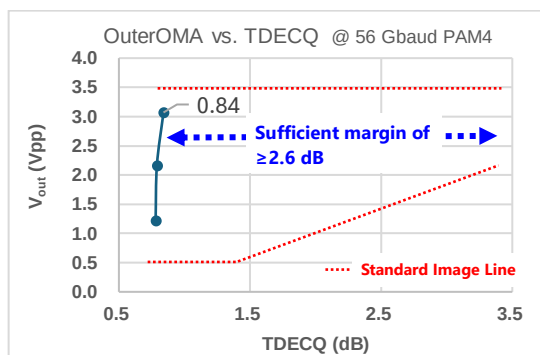


$V_{in} = 0.35 \text{ Vpp}$, $R_{LM} = 0.979$, TDECQ = 0.69 dB



$V_{in} = 0.50 \text{ Vpp}$, $R_{LM} = 0.945$, TECQ = 0.84 dB

56 Gbaud PAM4 Waveform



Outer OMA vs. TDECQ/ R_{LM} Example (@ 56 Gbaud PAM4)

The above shows an image of the TDECQ evaluation margin for an optical device when using these signal sources. In addition to complying with regulations at the data rate used, it is essential to ensure adequate margins at each output state from the point of view of digital communication reliability.

7. Conclusion

The different evaluation items of optical devices require different measurement items and evaluation complexity. It is also necessary to perform conformance testing with adaptive standards and other products. Anritsu wideband linear amplifiers with high output power of 3.1 Vpp at 56 Gbaud are ideal for evaluating the performance of SiPh/DML optical devices. Anritsu is continuing to provide customers with the latest measurement solutions.



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