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Feasibility study of 100G/lambda Nyquist-PAM4 with commercially available 1.3um/1.5um EML

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Previous contributions

We have proposed Nyquist modulation for 2- and 10-km SMF PMD;

Features
- Narrow spectrum by Nyquist pulse shaping
- Reduction of ADC/DAC's sampling rate
- Simple IM/DD configuration
- Simple DSP
- High Rx sensitivity and high CD tolerance

This presentation

We study the following items for consideration of baseline proposal;

- Feasibility study with commercial EMLs used in 100GbE transceiver
- Comparative study between Nyquist-PAM4 and conventional PAM4

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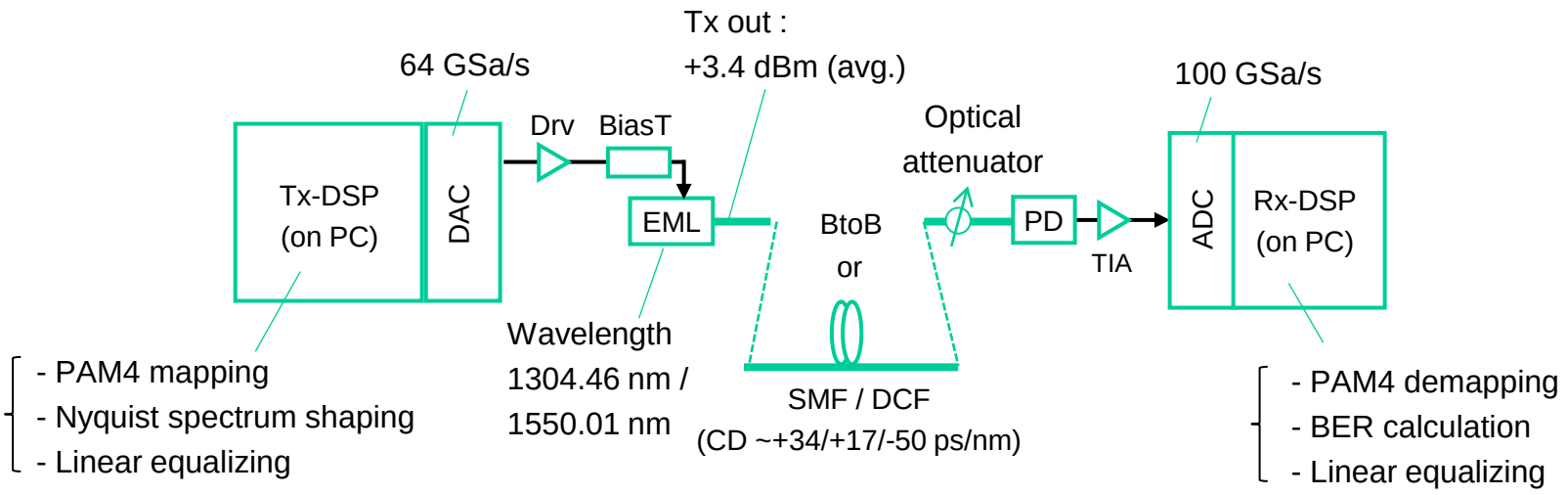
The following items are investigated to confirm practical use for 400GbE;

1) Comparison between EML and LN-MZ

2) Applicability of commercial 25G-class 1.3um EML

3) Estimation of dispersion penalty with commercial EML

Experimental setup



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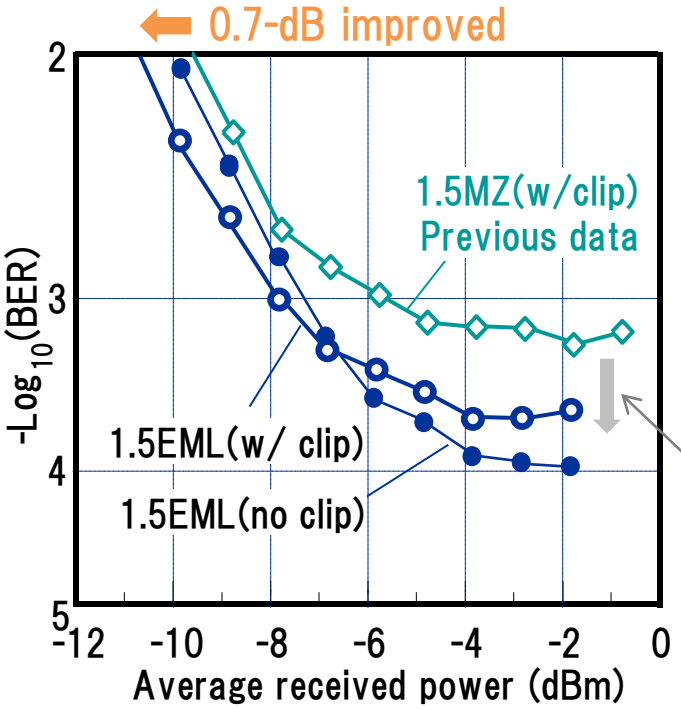
Experimental condition

Parameters	Values	Remarks
Tx (DAC, driver, modulator) BW	14 GHz	
DAC sampling rate	64 GSa/s	
Rx (PD-TIA, ADC) BW	33 GHz	
ADC sampling rate	100 GSa/s	
Wavelength	1304.46 nm / 1550.01 nm	1.3um EML / 1.5um EML
Modulator	EML	1.3um EML BW : ~23 GHz, Vmod: ~1.5 V, ACER: ~8 dB
Modulation format	Nyquist-PAM4	51.2-Gbaud
Roll-off factor	0.1	For Nyquist modulation
Number of taps	101	
Total data rate	102.4 Gbit/s	
Pattern length	32768 (= 2^15)	(Random pattern not used)

2-1. Comparison between EML and LN-MZ

- LN-MZ modulator was used in the contribution shown at July meeting.
- For practical implementation, we study possibility of the usage of EML.
- 1.5-um devices are prepared in order to ignore λ-dependent difference.



Received power vs. BER

Specification of modulators

	MZ	1.5um EML
Vmod	4.7 V (Vpi)	3.0 V *
Bw	36.5 GHz	30 GHz

* Peak to peak ER=10 dB

* BER floor is mitigated by improved DAC equalization from the previous experiment

✓ With EML(1.5um), 0.7-dB higher sensitivity is achieved.

- Low Vmod results in larger modulation amplitude
- Effect of reduced modulator bandwidth is negligible

2-2. Applicability of commercial 25G-class 1.3um EML

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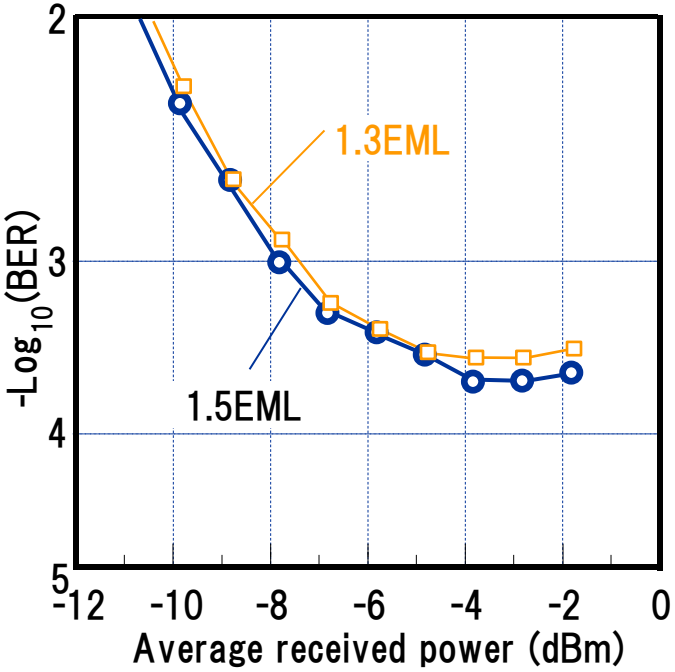
Performance with 1.3um EML used in 100G CFP2 is evaluated.



Received power vs. BER

Specification of modulators

	1.5um EML	1.3um EML
Vmod	3.0 V	1.5 V
Bw	30 GHz	23 GHz

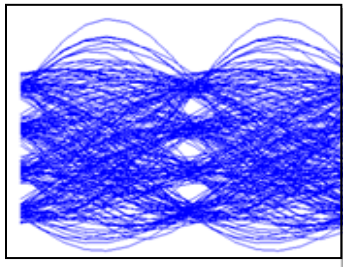
1.3um EML
100G CFP2-LR4 TOSA
Oclaro TRB5E20

Performance

	1.3um EML
Tx output	+3.4 dBm (avg.)
Rx sensitivity	-8.5 dBm (avg.)

Δ11.9 dB

Input BER = 2E-3
Output BER = 1E-13



Received waveform

- ✓ 1.3um EML as 100G CFP2-LR4 TOSA is applicable with almost the same performance as 1.5um EML with 30-GHz bandwidth.
- ✓ 11.9-dB experimental budget is achieved. Capability of 10km SMF transmission is shown.

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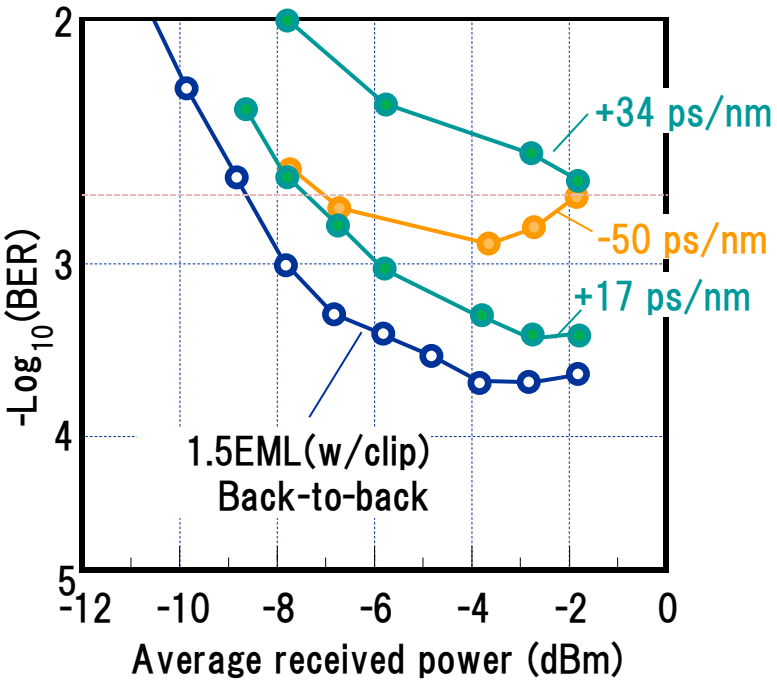
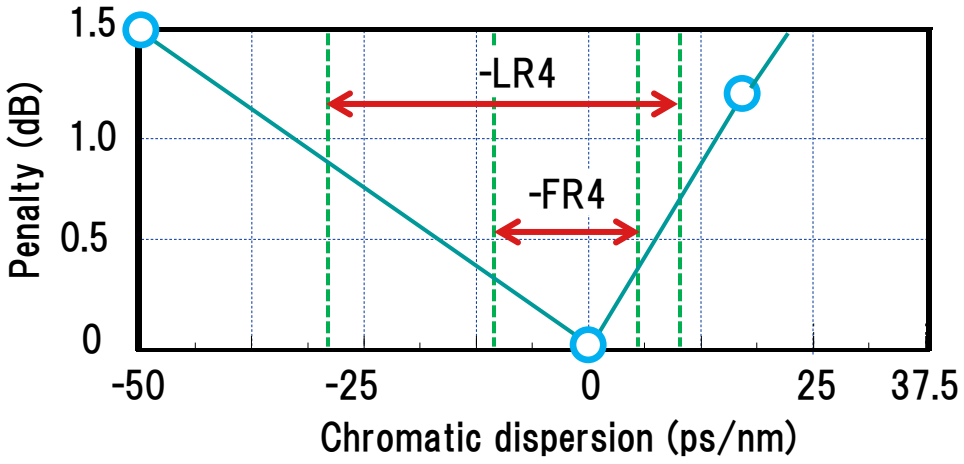
Dispersion penalty is estimated with 1.5um EML for dispersion tuning.



Received power vs. BER

Center Wavelengths

	-FR4	-LR4
	CWDM	LANWDM
L0	1271 nm	1295.56 nm
L1	1291 nm	1300.05 nm
L2	1311 nm	1304.58 nm
L3	1331 nm	1309.14 nm



Chromatic dispersion vs. penalty

✓ Feasibility of 2- and 10-km transmission is shown
-FR4: dispersion penalty is negligible small (~ 0.3 dB)
-LR4: dispersion penalty is < 1.0 dB

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In July meeting, there was questions about the performance difference between Nyquist-PAM4 and conventional PAM4.

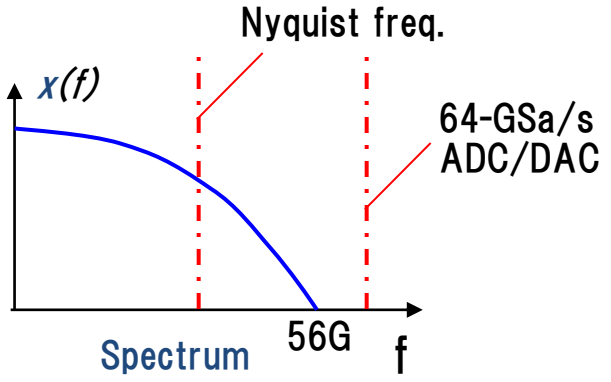
Basic idea of Nyquist modulation

1) Background
- 64-GSa/s ADC / DAC are commercially available
- Nyquist freq. is 32 GHz

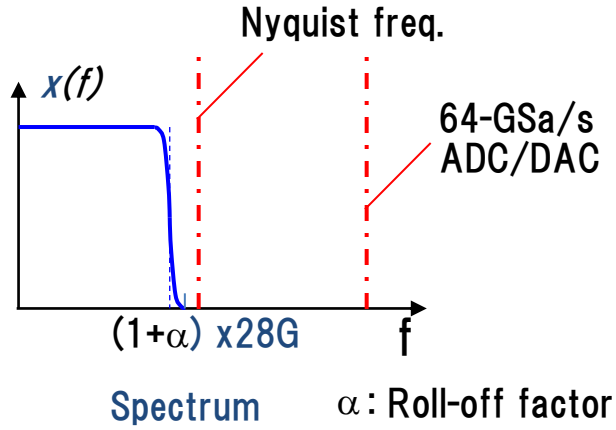
2) Signal bandwidth vs. Sampling rate
- Bw of conventional PAM4 exceeds Nyquist freq.
- Bw of Nyquist-PAM4 falls within Nyquist freq.

3) Advantage of Nyquist modulation
- 64-GSa/s ADC/DAC can be used
- Required bandwidth of components is mitigated

112Gbit/s (56GBaud) PAM4



112Gbit/s (56GBaud) Nyquist-PAM4



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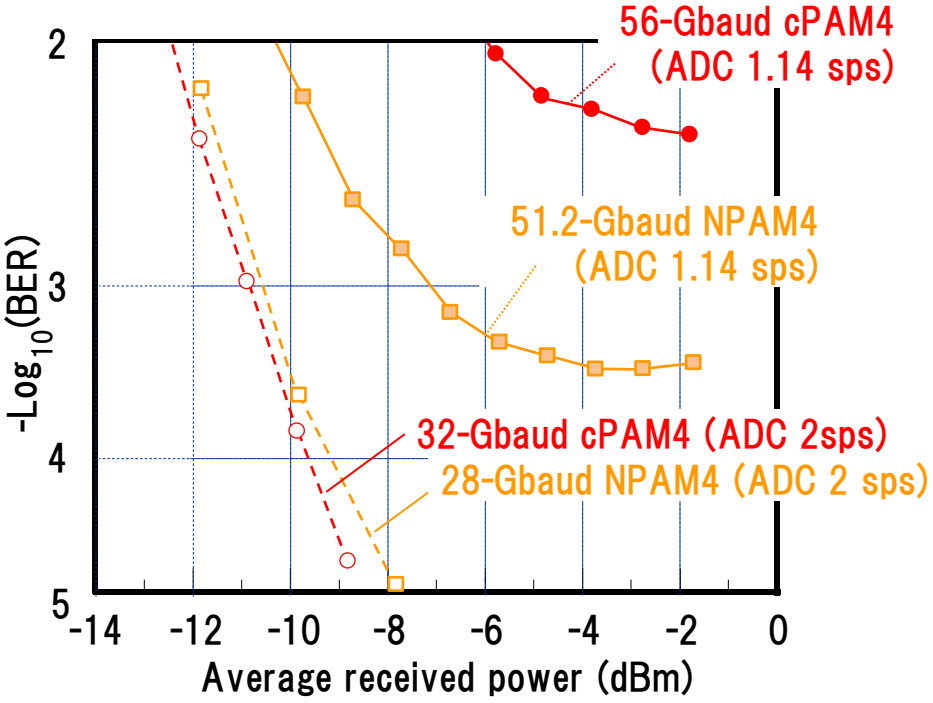
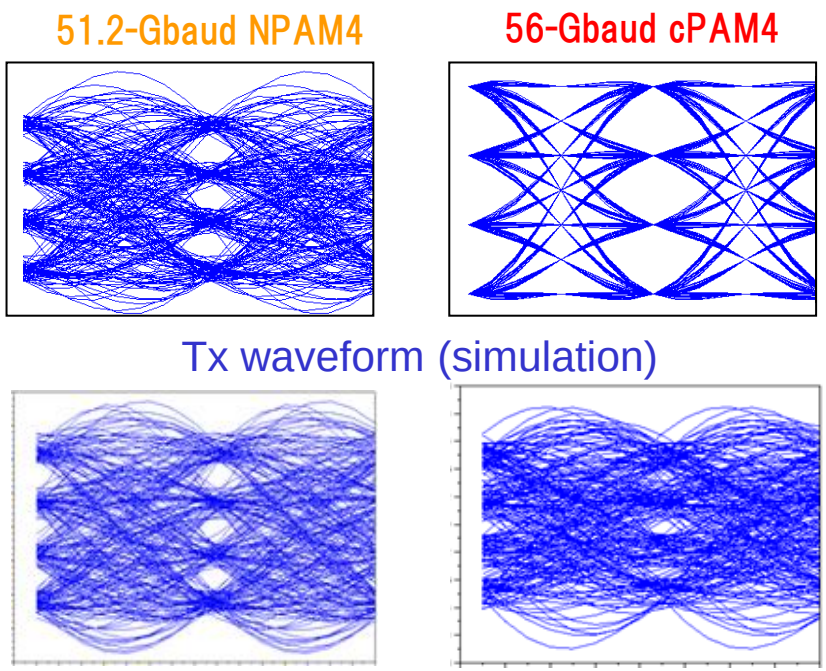
- Performance difference is experimentally investigated with common DSPs
- Sampling rate is limited to 1.14 (=64/56) sps by digital signal processing.



Received power vs. BER



Tx waveform (simulation)

Received waveform (experiment)

✓ In case with ideal 2-sps(sample per symbol) sampling,
conventional PAM4 shows slightly better performance than Nyquist-PAM4.

✓ In case with less than 2-sps sampling,
conventional PAM4 shows poor performance.

4. Summary

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1) Our study confirms 400GbE using Nyquist-PAM4 is possible with commercial available EMLs used in 100GbE transceivers, which shows the following performance;

- High Rx sensitivity

  -8.5 dBm(avg.) @ BER=2E-3 (Tx out : +3.4 dBm(avg.))

  ➡ 11.9-dB budget is achieved experimentally.

- High CD tolerance

  Less than ~1.0 dB @ -LR4
  Less than ~0.3 dB @ -FR4

  ➡ Feasibility of 2- and 10- km transmission are shown.

2) Comparative study between Nyquist-PAM4 and conventional PAM4 shows;

ADC/DAC with ideal 2-sps(sample per symbol) sampling:
➡ conventional PAM4 shows slightly better performance than Nyquist-PAM4.

ADC/DAC with less than 2-sps sampling:
➡ conventional PAM4 shows poor performance.

Thank you