400GE 2-km and 10-km SMF PMD Proposals and Experimental Verification with Nyquist Modulation

Riu Hirai, Hidehiro Toyoda, Nobuhiko Kikuchi
Hitachi Ltd.

IEEE 802.3bs 400GE Task Force
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1. Introduction

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Previous contribution "Hirai_400_01_0114"

400GE PMD should satisfy the following items;
- Common signaling format for wide transmission range
- 4-lambda x 100G configuration for compatibility with 100GBASE-LR4
- Simple configuration and simple DSP
- Sufficient power budget enough to realize 10-km SMF transmission

We proposed Nyquist modulation schemes for 400GE PMD,
covering 500-m ~ 10-km SMF transmission with 4-lambda x 100G configuration.

Nyquist-SCM(Subcarrier modulation) with ≥ 16-level (~ 25 Gbaud)

Nyquist-PAM4~8 (~ 50 Gbaud)

2. Scope

In this presentation,
we show experimental verification of Nyquist-PAMn (n = 4)*,
and provide some specification proposals to support the following objectives.

802.3bs adopted objectives - Mar 2014, 802.3 WG :

Provide physical layer specifications which support link distances of:
At least 2 km over SMF
At least 10 km over SMF

*Note; Nyquist-SCM with 16 levels at 14 Gbaud already has been experimentally demonstrated with an optical pre-amplifier and dual-polarization (56 Gbps/ pol.) by J C Cartledge, et al., ECOC2013 We.4.C.3.

3. Principle of proposed Nyquist modulation

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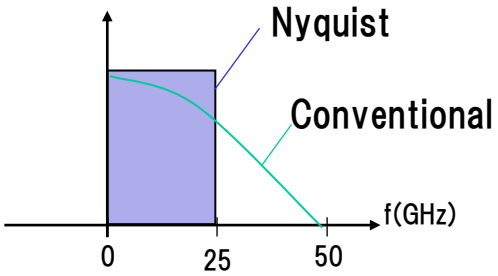
Motivation

- To achieve high Rx sensitivity and high CD tolerance, the use of DSPs becomes unavoidable.
- The number of signal levels should to be as few as possible (~ 4), since Rx sensitivity drop rapidly as it increases. (But signal baud rate increases.)
- To cover 50-GHz frequency range (e.g. 50-Gbaud PAM4), sampling rate of ADC/DACs should surpass 100-GSa/s. However sampling rate of ADC/DAC is desired to be less than ~60-GSa/s.

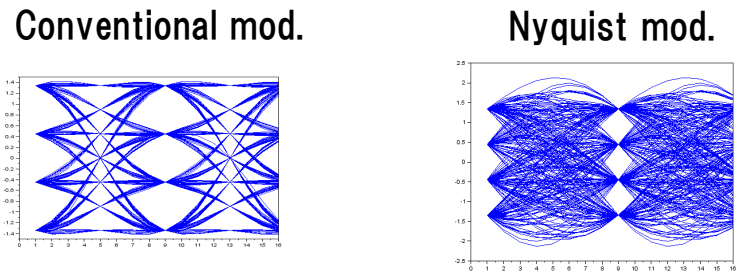
Currently available

Nyquist modulation

For reduction of ADC/DAC's sampling rate, spectrum compression by Nyquist pulse shaping is one promising way.



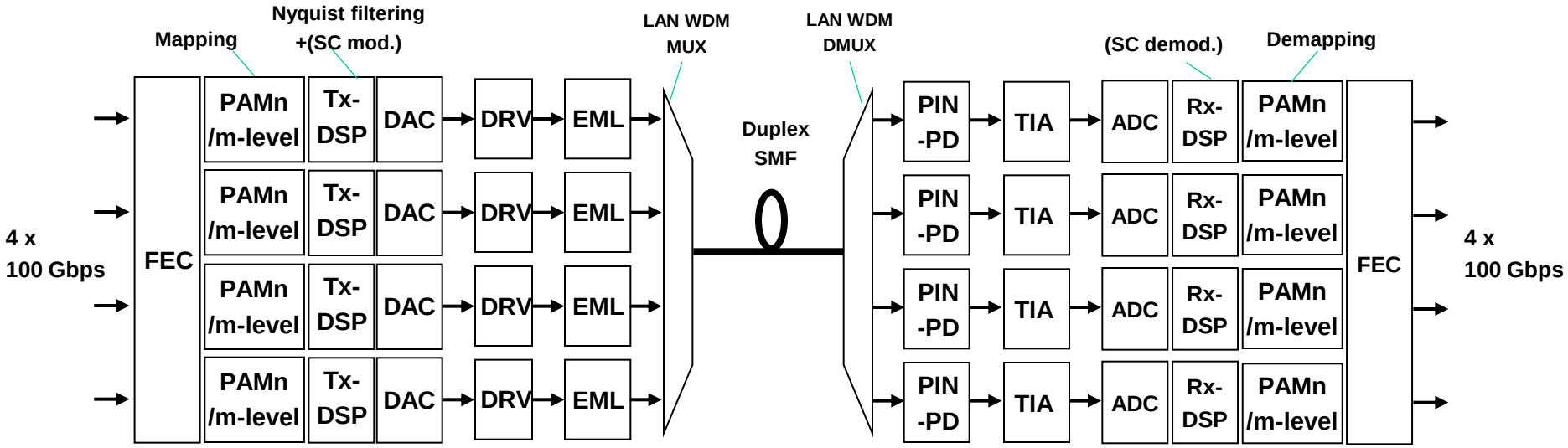
Electrical spectrum comparison



Waveform comparison
e.g.) PAM4 modulation w/ or w/o Nyquist pulse shaping

4.1. Configuration

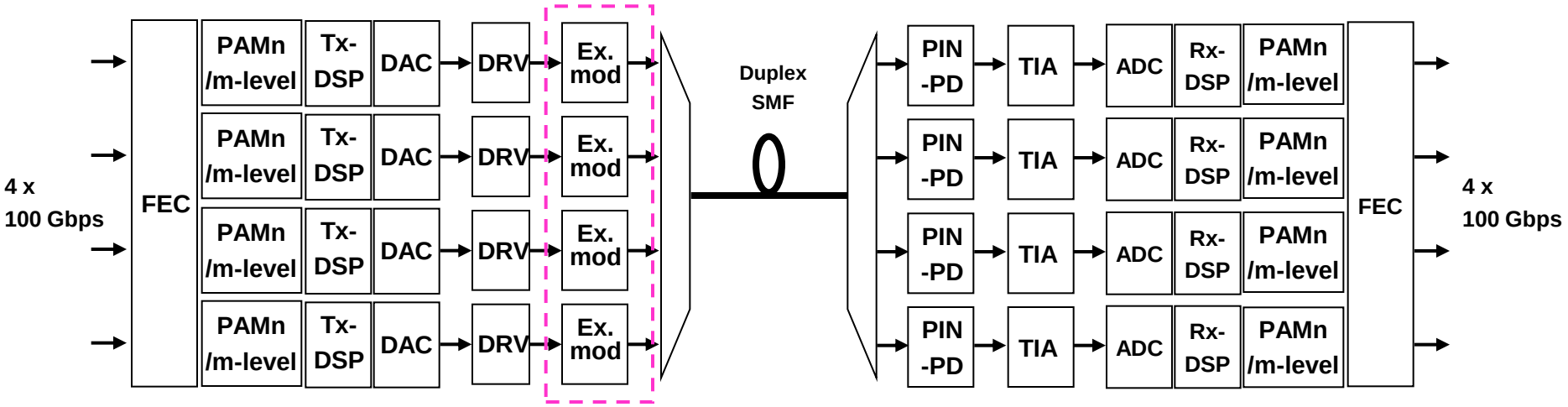
Block Diagrams for 2-km SMF PMD



- EML : EA - DFB
- Tx-DSP : Nyquist filtering + Linear equalizing + (Subcarrier modulation), etc
- Rx-DSP : Adaptive equalizing + (Subcarrier demodulation), etc

4.2. Configuration (Cont'd)

Block Diagrams for 10-km SMF PMD



- Ex. mod: IQ-modulator + DFB (or EA + DFB)
- Tx-DSP : Nyquist filtering + Linear equalizing + (Subcarrier modulation), etc
- Rx-DSP : Adaptive equalizing + (Subcarrier demodulation), etc

5.1. Experimental verification

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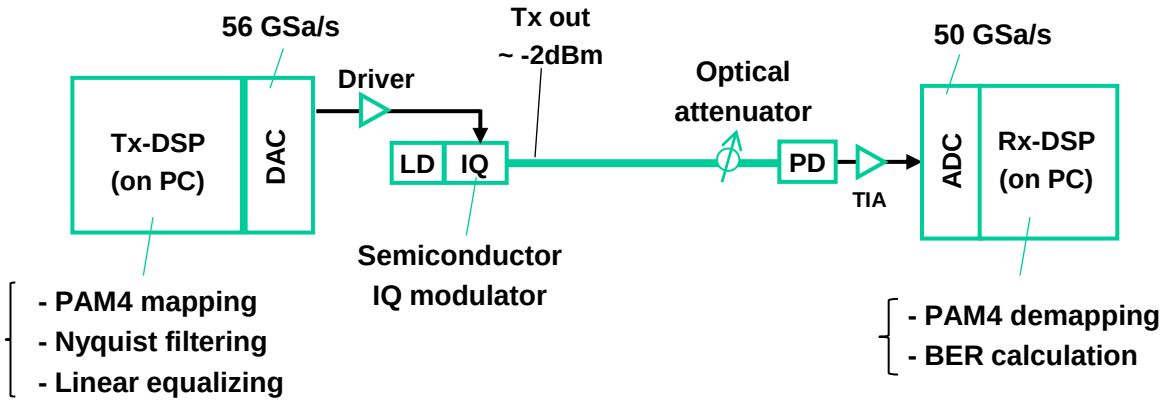
Verification item

- Experimental confirmation of Nyquist-PAMn scheme
- Early study of Rx sensitivity

Experimental setup

- Data rate 56 Gbps; half-rate signaling due to insufficient DAC bandwidth
- Single 1.5-μm wavelength LD, no WDM
- One branch of semiconductor IQ-modulator
- No optical amplifier
- Digital Signal Processing on offline PC
- Nyquist-PAM4



5.2. Experimental verification (Cont'd)

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Experimental condition

Parameters	Values	Remarks
DAC + linear driver 3dB-bandwidth	14 GHz	
DAC sampling rate	56 GSa/s	
Receiver + ADC 3dB-bandwidth	22 GHz	
ADC sampling rate	50 GSa/s	
Wavelength	1.5-μm band	
Modulator	Semiconductor IQ-modulator	
Signaling format	Nyquist-PAM4	
Raised-cosine filter	101 Tap / Roll-off 0.1	
Total data rate	56 Gbps	Half-rate

5.3. Experimental verification (Cont'd)

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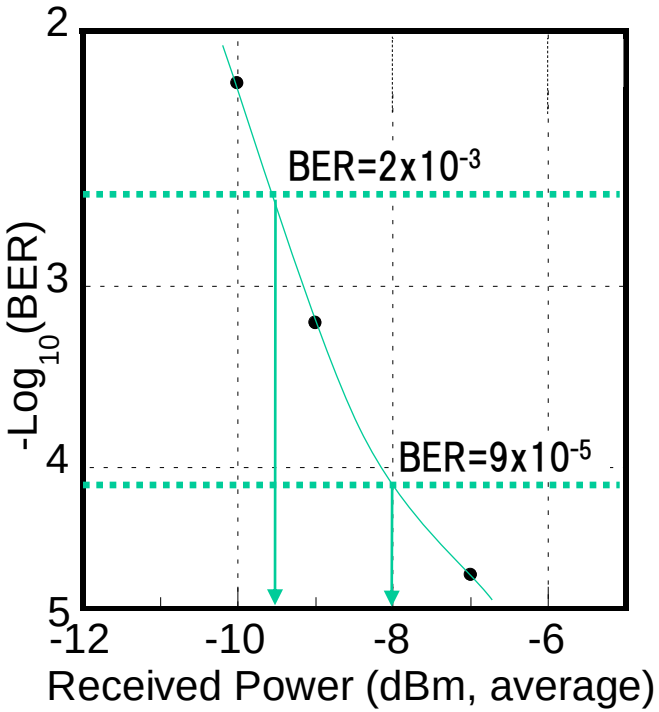
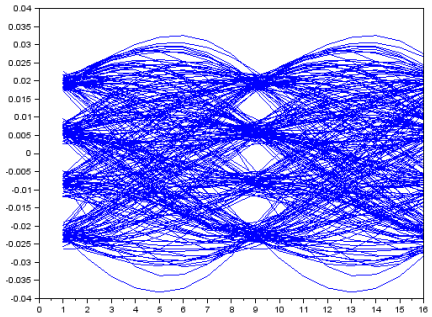
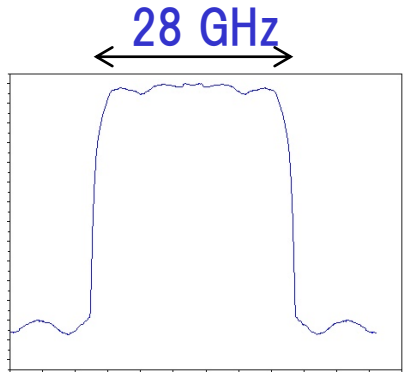
Experimental results



Received power vs. BER
(56-Gbps Nyquist-PAM4)



Received waveform



Frequency spectrum

Rx sensitivity comparison

FEC	Input BER *	Rx sensitivity
Super FEC	2×10^{-3}	-9.5 dBm
bj FEC	9×10^{-5}	-8.0 dBm

* Output BER = 1×10^{-13}

- We experimentally verified the principle with half-rate (56-Gbps) signaling.
- Rx sensitivity at full-rate (100-Gbps) signaling is estimated to be ~ -6.5 dBm.

(with Super FEC)

6. Summary

In this presentation, for 400GE 2-km and 10-km SMF PMD proposal,
we reviewed our proposed schemes which presented at Indian Wells meeting,
and experimentally verified Nyquist-PAMn (n = 4).

Features

- 4-lambda x 100G configuration with Nyquist modulation
  covering 500 m – 10 (or beyond 10) km over SMF
- Simple Tx/Rx configuration (Single modulator + Single PD, w/o optical amp.)
- High CD tolerance with digital predistortion
- Simple DSP

Future works

We will provide the following specifications
for 400GE 2-km and 10-km SMF PMD baseline proposal;

- Tx output power
- Rx sensitivity
- Dispersion and other penalties
- FEC

… etc.

Thank you