HITACHI
Inspire the Next

Proposal Updates of Nyquist Modulation

Riu Hirai, Hidehiro Toyoda, Nobuhiko Kikuchi
Hitachi Ltd.

IEEE 802.3bs 400GE Task Force
IEEE 802 Plenary Session
July 13 - 18, 2014 San Diego, CA USA

Supporters

Atsushi Takai, Oclaro, Inc.

Ram Rao, Oclaro, Inc.

Kiyo Hiramoto, Oclaro Japan, Inc.

Masashi Kono, Hitachi Ltd.

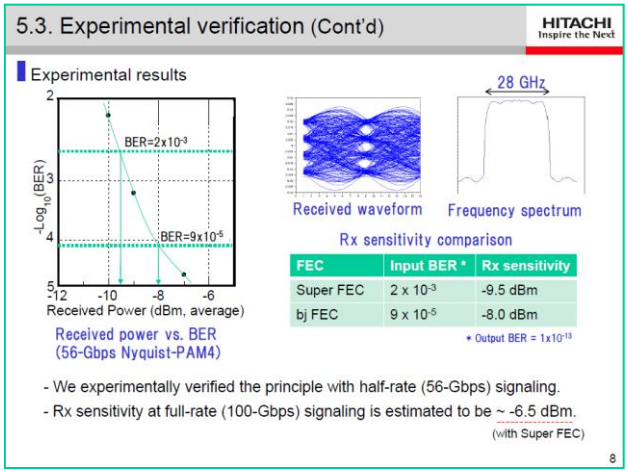
HITACHI
Inspire the Next

Previous contributions

At Indian Wells meeting in Jan. 2014,
we proposed the following signaling formats for 2-km and 10-km SMF PMD;

- Signaling format with 4-lambda x 100G configuration
  Nyquist-PAM and Nyquist-SCM(Subcarrier modulation)
- Simple Tx/Rx configuration (Single modulator + Single PD)
  Short reach version(ex. ≤ SMF 2 km): 1.3-μm EML/DML + PD + TIA
  Long reach version(ex. ≥ SMF 2 km): 1.3-μm DFB + IQM/MZM +PD + TIA
- High Rx sensitivity and high CD tolerance
- Simple DSP
- Reduction of ADC/DAC's sampling rate

At Norfolk meeting in May 2014,
we shown technical feasibility
with Half-rate(56Gbit/s/lambda) Nyquist-PAM4.



Hirai_3bs_01_0514.pdf

2. Motivation

HITACHI
Inspire the Next

1) Comparison between Nyquist-PAM and Nyquist-SCM

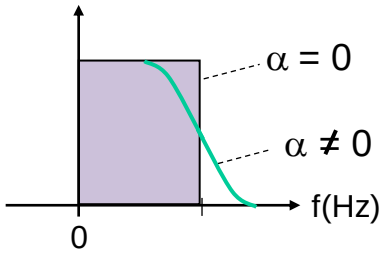
2) Experimental demonstration of 100Gbit/s/lambda Nyquist-PAM4 signaling with commercially available ADC and DAC

HITACHI
Inspire the Next

Verification item

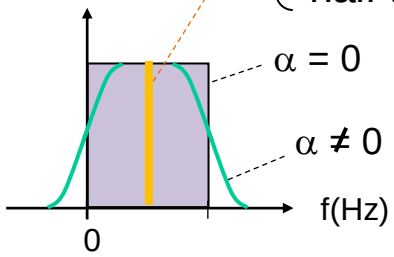
1) Rx sensitivity

2) Influence of Roll-off factor (α)



Nyquist-PAM4

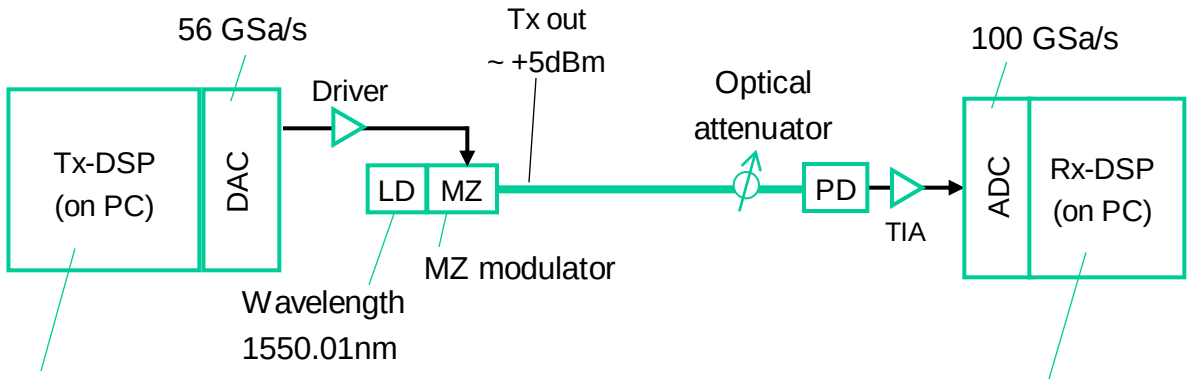
Half-cycle subcarrier
(Subcarrier freq. is half the symbol rate)



Nyquist-SCM-16QAM *

*Note;
100 Gbit/s/lambda with SCM-32QAM (subcarrier freq. is one-third symbol rate) has been demonstrated with simulation by W. Ling, I. Lyubomirsky, et al., Optics Express, Vol. 22, Issue 9, pp. 10844-10857, 2014.

Schematic of Experimental setup



- PAM4 / 16QAM mapping
- Nyquist spectrum shaping
- Linear equalizing
- (SCM processing)

- Rectangular filter for noise reduction
- PAM4 / 16QAM demapping
- BER calculation
- (SCM processing)

HITACHI
Inspire the Next

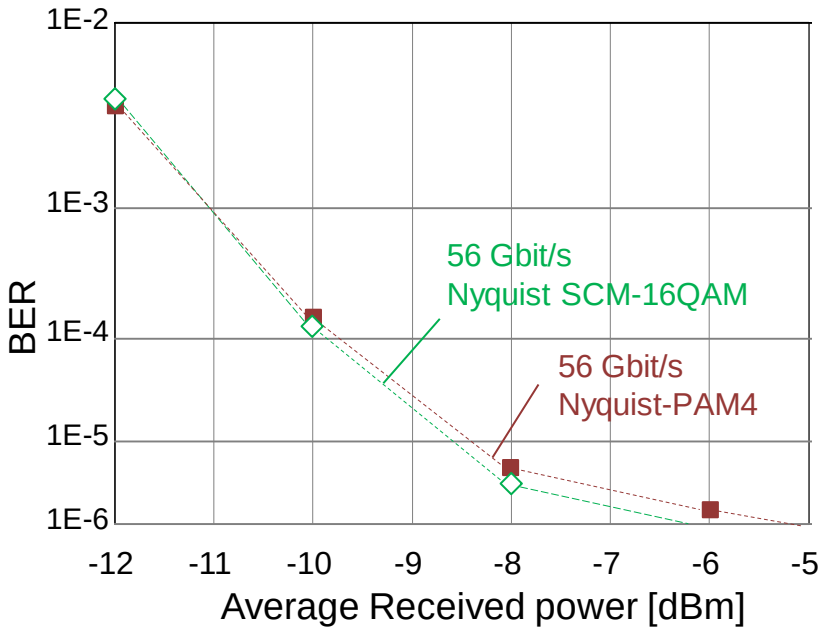
Experimental condition

Parameters	Values	Remarks
Tx (DAC, driver, modulator) BW	14 GHz	
DAC sampling rate	56 GSa/s	
Rx (PD-TIA, ADC) BW	33 GHz	
ADC sampling rate	100 GSa/s	
Wavelength	1.5-μm band	
Modulator	MZ-modulator	
Modulation format	Nyquist-PAM4 Nyquist-SCM-16QAM	28-Gbaud 14-Gbaud
Roll-off factor	0	Raised-cosine filter
Number of taps	10001	Ideal rectangular spectrum
Total data rate	56 Gbit/s	Half-rate
Pattern length	32768 (= 2^15)	

HITACHI
Inspire the Next

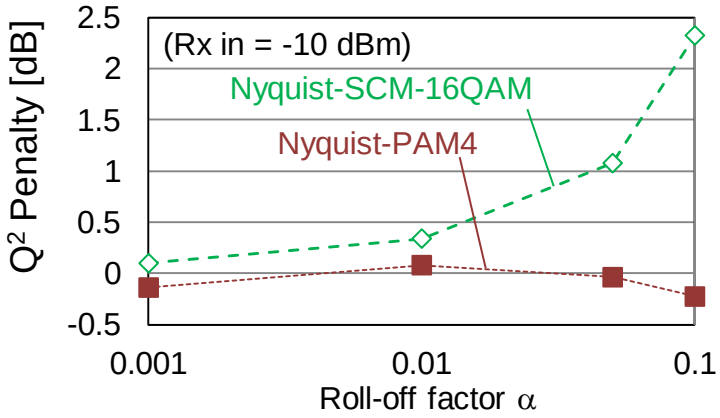
Experiment results

1) Rx sensitivity measurement

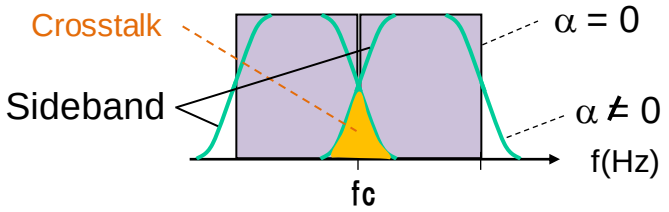


Received power vs. BER (Roll-off factor = 0)

2) Influence of Roll-off factor



Roll-off factor vs. Q^2 penalty



Optical spectrum of Nyquist-SCM-16QAM

- In terms of Rx sensitivity,
  the difference between Nyquist-PAM and Nyquist-SCM is negligible ($\alpha = 0$).
- As roll-off factor increases ($\alpha > 0$), penalty of Nyquist-SCM signal increases due to crosstalk between sidebands. It needs guard-band and a bit more bandwidth.

HITACHI
Inspire the Next

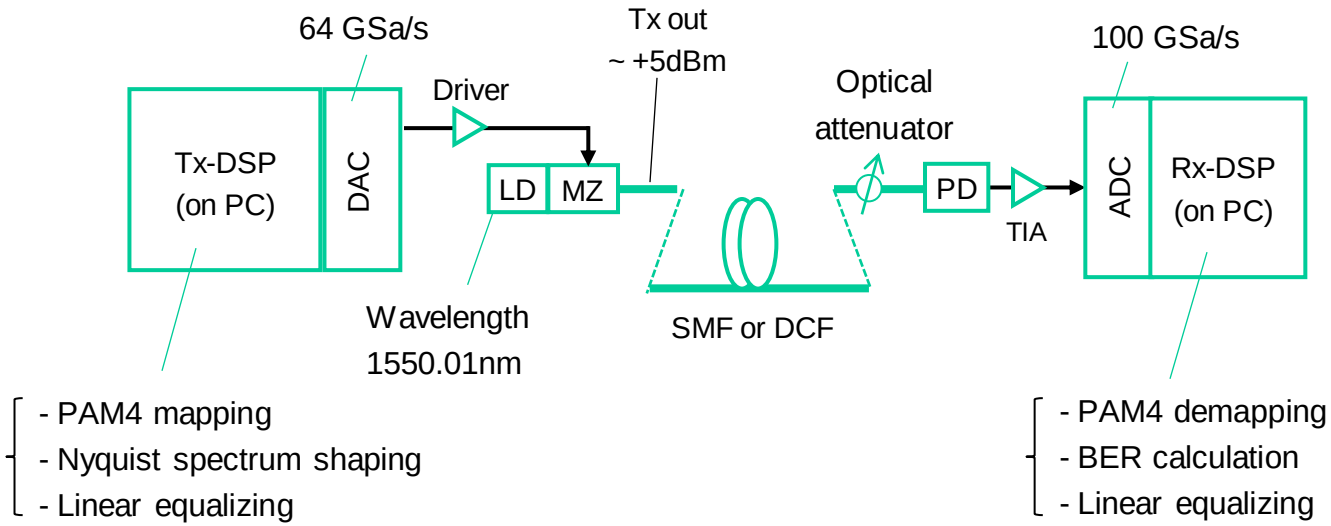
Purpose

1) First experimental demonstration of 100Gbit/s/lambda with Nyquist-PAM4

2) Verification of reduction of ADC/DAC's sampling rate by Nyquist modulation i.e. 50-Gbaud class signal generation with the use of 60-GSa/s class DAC

3) Confirmation of high Rx sensitivity and high CD tolerance

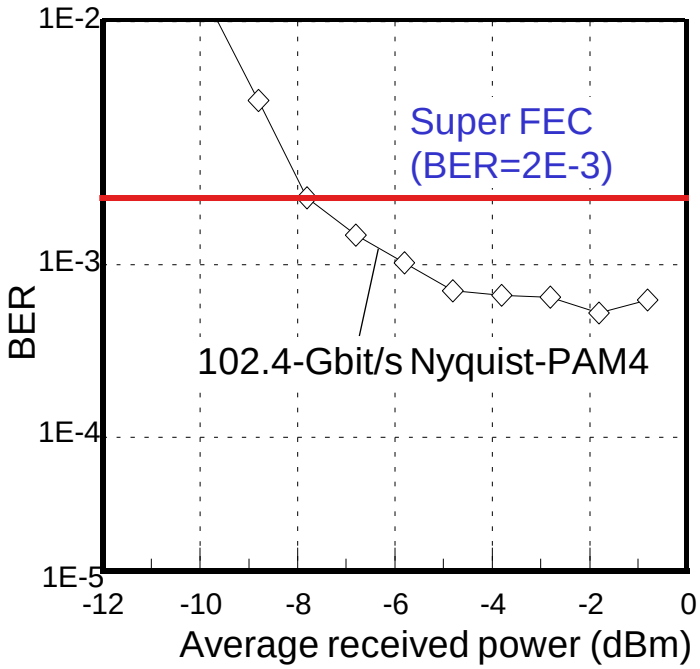
Experimental setup



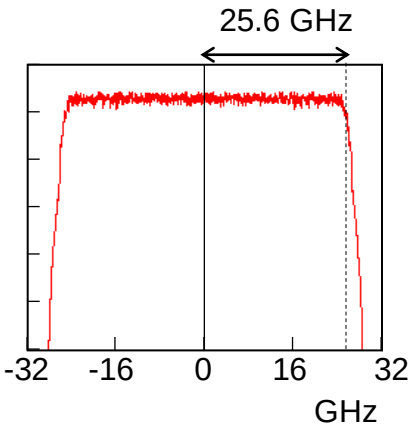
- 51.2-Gbaud Nyquist-PAM4
- Commercially available DAC (64 GSa/s, Bw:~15 GHz)
- Raised cosine filter (101 taps, Roll-off factor 0.1)

HITACHI
Inspire the Next

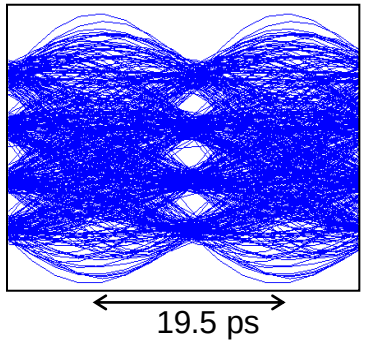
Experiment results



Received power vs. BER
(Back-to-back)



Frequency spectrum



Received waveform

Rx sensitivity

FEC	Input BER	Rx sensitivity
Super FEC	2E-3	-7.8 dBm

Output BER = 1E-13

- 100Gbit/s/lambda Nyquist-PAM4 signaling is realized with 64-GSa/s DAC.
- High Rx sensitivity is confirmed.
- 2-km SMF transmission is experimentally verified.*
  (wavelength = 1550.1nm, CD = +/-34ps/nm)

** Detailed results will be presented at ECOC 2014.*

HITACHI
Inspire the Next

1) Comparison between Nyquist-PAM4 and Nyquist-SCM-16QAM

In case of ideal rectangular spectrum, they have almost the same Rx sensitivity.
Nyquist-SCM requires a bit more complex implementation with guard-band.

2) Experimental demonstration of 100Gbit/s/lambda

We realize 100Gbit/s/lambda Nyquist-PAM4 signaling
with 60-GSa/s class DAC and ADC*.

** We also have been confirmed to able to receive at ADC sampling rate with 1.25 times symbol rate by using 42.67-Gbaud signal.*

Future works

- Experimental verification of 2-km or 10-km SMF transmission with 1.3-μm band

- Estimation of power consumption

Thank you