Experimental Demonstration of 56Gbps NRZ for 400GbE 2km and 10km PMD Using 100GbE Tx & Rx with Rx EQ

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Contents

Introduction

- 56Gb/s NRZ considered a promising candidate for 400GbE PMD due to its simplicity, high sensitivity, and high tolerance to MPI:

  cole_01_0914_smf.pdf; qian_3bs_01_0714.pdf; zhu_3bs_01a_0514.pdf;

  zhu_3bs_01_0714.pdf; shirao_3bs_01a_0714.pdf; stassar_01_1014_smf.pdf

- In *wen_3bs_01_0914.pdf*, we demonstrated 56Gbps NRZ for 400GbE PMD using 43G optical transmitter and receiver without using Rx equlaization.
- *lyubomirsky_400_01_1113* simulated, and *wen_3bs_02a_1114.pdf* demonstrated 56Gbps NRZ for 400GbE PMD using 28G optical transmitter and 43G receiver.
- It is desirable to use 28G optics for both transmitter and receiver.
- In *wen_3bs_01_1114.pdf,* we also demonstrated that there is no difference between prbs31 and prbs15 for NRZ performance. But we will address the request to use SSPR pattern for NRZ test as well.

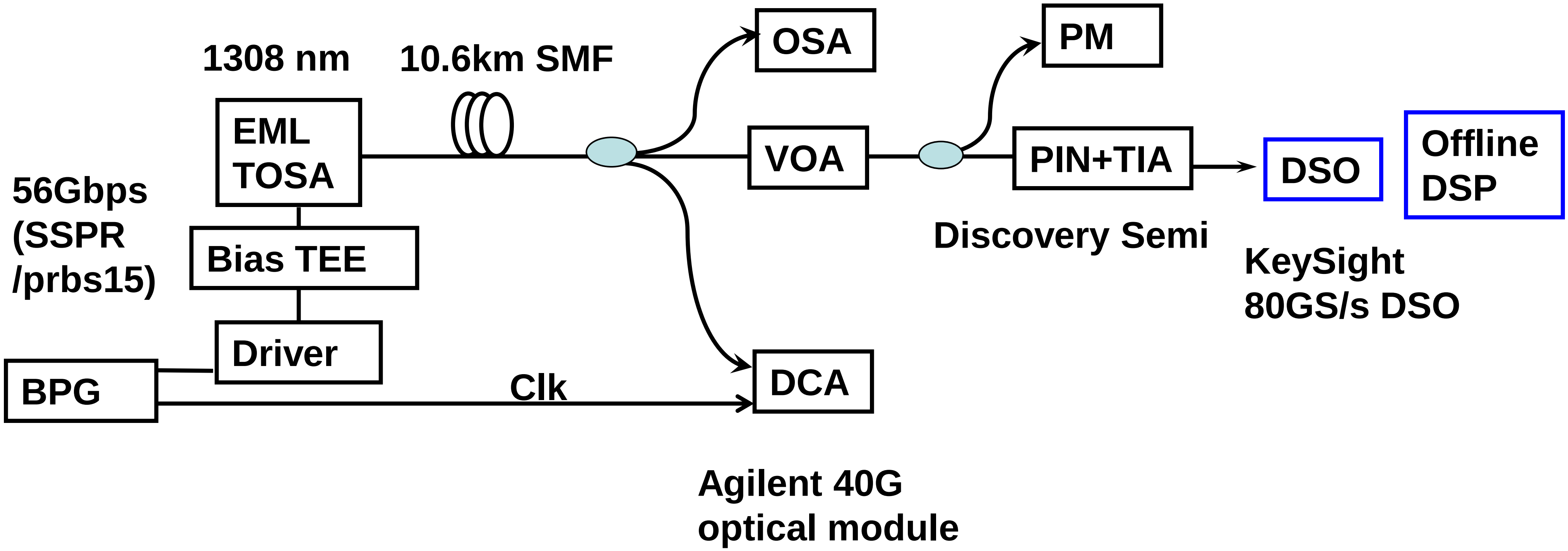
Work in this Presentation

- In this presentation, we

  - Demonstrate the feasibility of 56Gbps NRZ for 400GbE PMD using 28G optical transmitter and receiver with Rx equalization

  - Present the 56Gbps NRZ performance using both prbs15 and SSPR

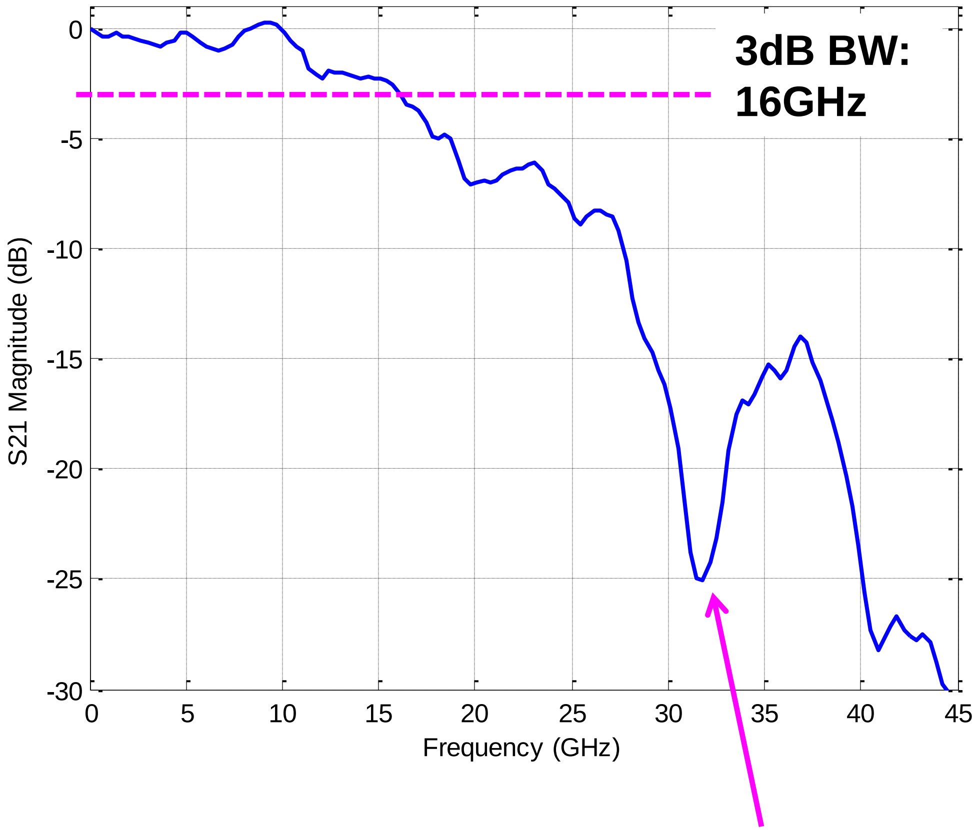
Experimental Setup



- Operation conditions of EML:
  - Laser bias current = 80mA
  - Operating temperature: 40 deg C
- Equalizer: FFE+DFE
- Discovery Semiconductor Receiver - R401HG, linear TIA

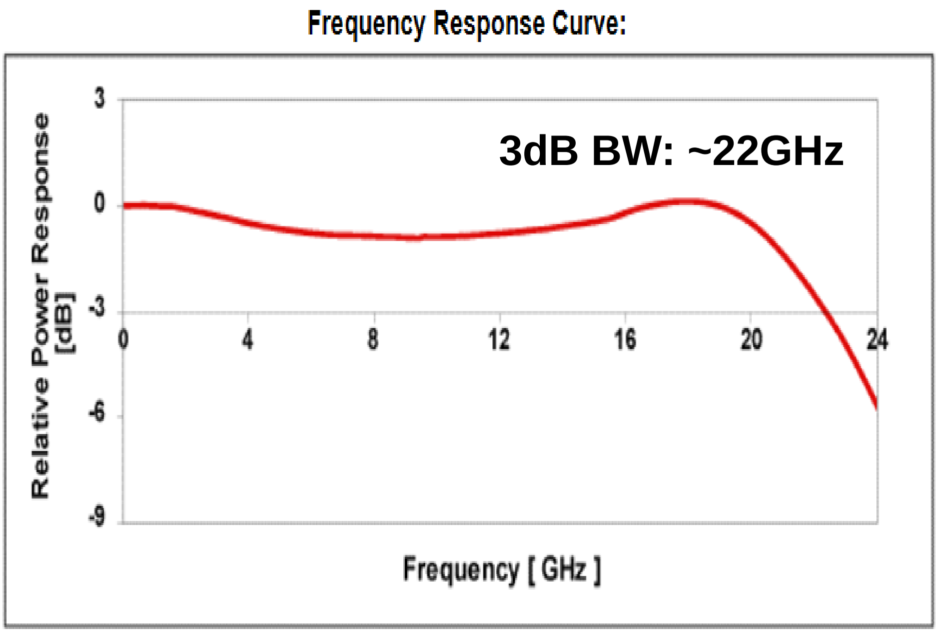
S21 of Transmitter and Receiver

Driver+ TOSA



Dip in response due to the TOSA packaging

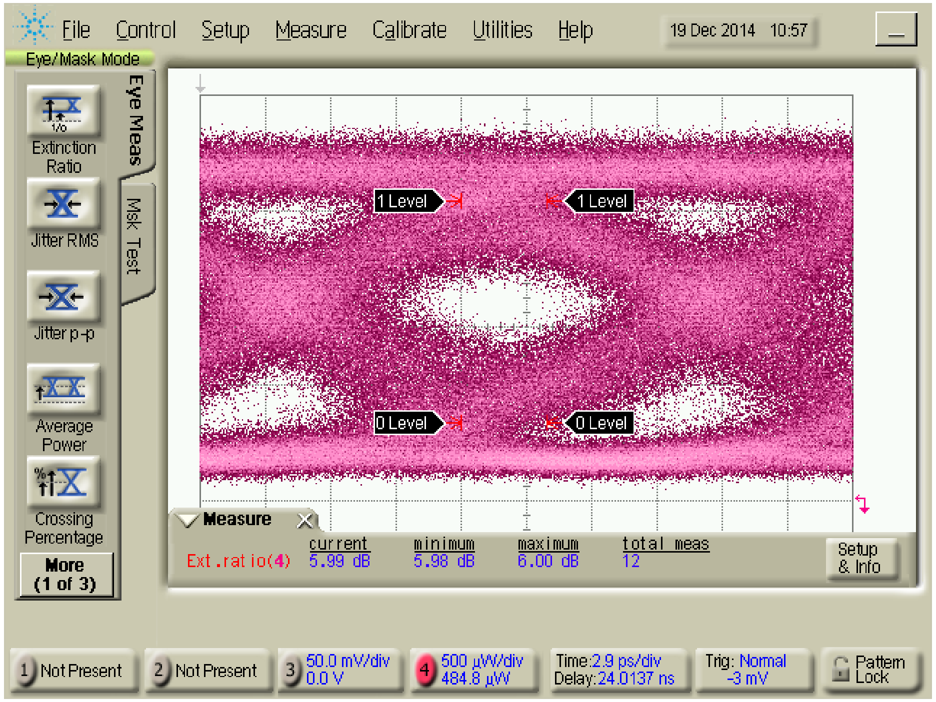
Discovery Semiconductor Receiver R401HG



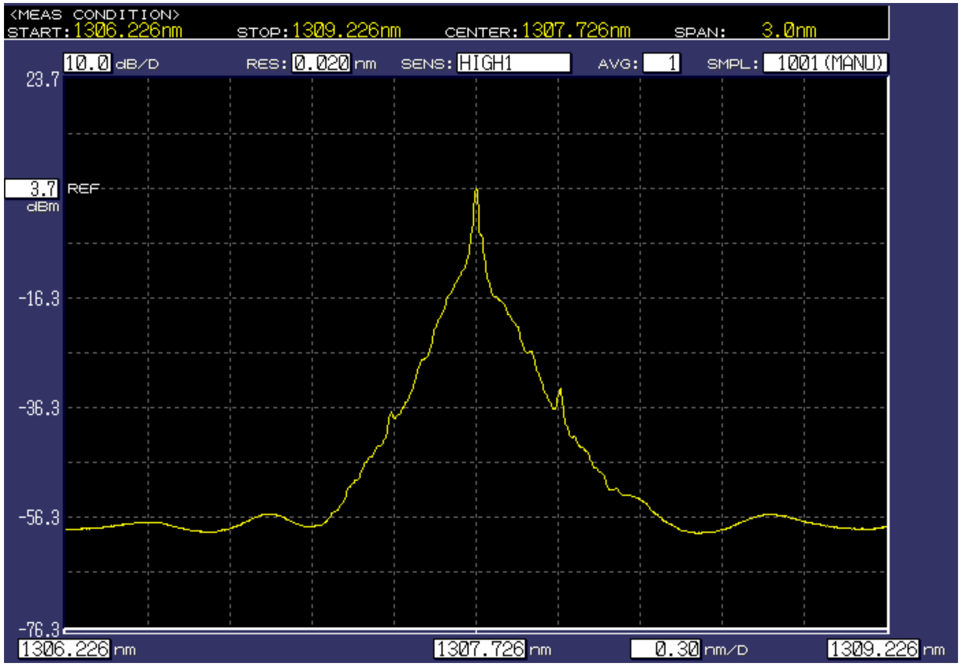
- **Typical responsivity at 1310nm: ~0.7A/W**
- **Typical input noise density: ~15pA/sqrt(Hz)**

Eye Diagram & Optical Spectrum – using SSPR

Eye Diagram

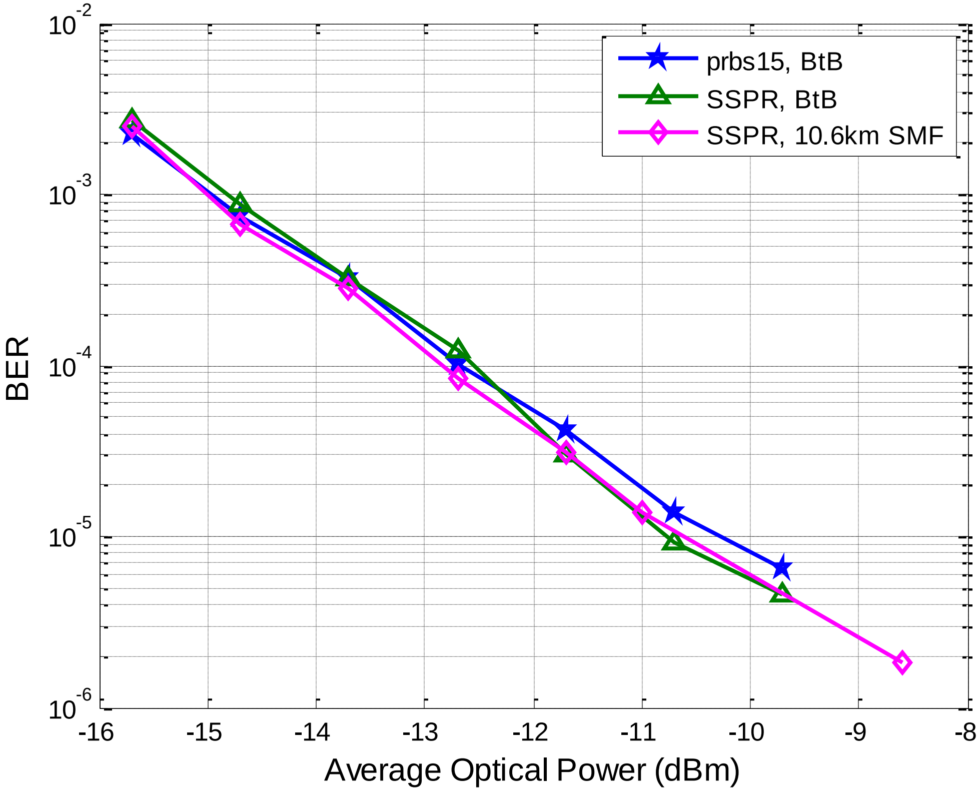


Optical Spectrum



- **Blurry optical eye observed for 56 Gbps data rate is due to transmitter band limitation**
- **ER = 6dB**

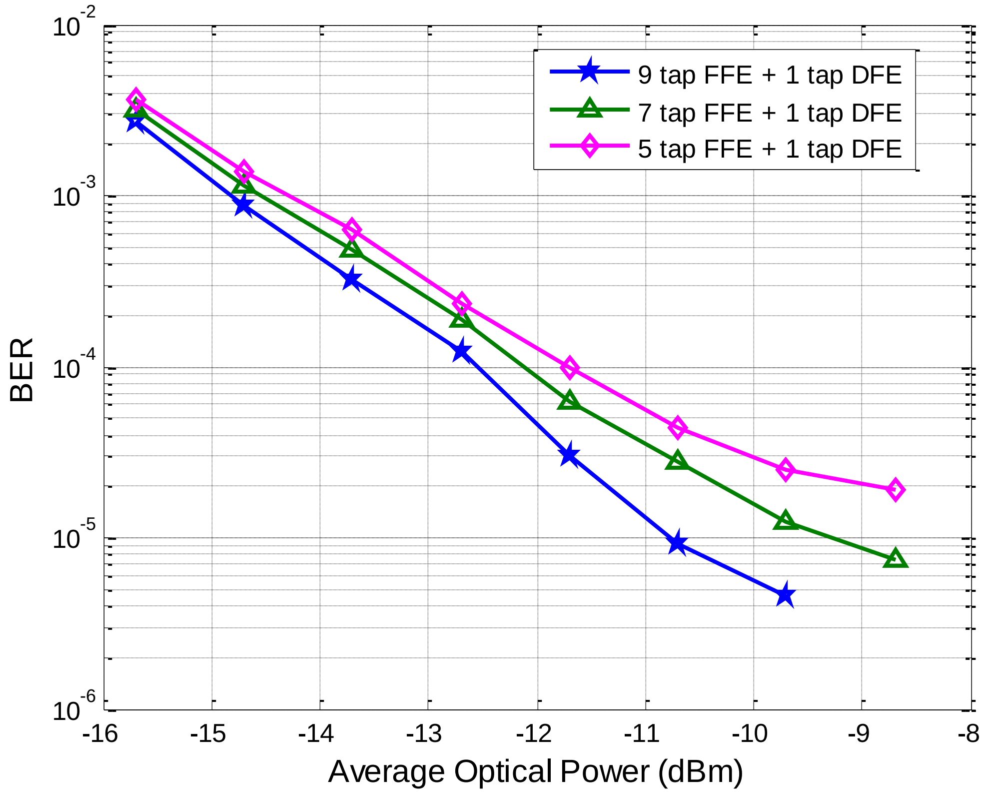
BER vs Average Optical Power



- **ER ~ 6dB**
- **9 tap FFE + 1 tap DFE**

- **No degradation in BER performance observed from prbs15 to SSPR for NRZ, which is different from that of PAM4**
- **With 9 tap FFE equalizer in Rx, the receiver sensitivity is around -13.2 dBm at BER@2e-4, and -14.8dBm at BER@1e-3**

Impact of Tap Number



- **ER ~ 6dB**
- **SSPR**
- **BtB**

- **The slight BER floor in case of 5-tap FFE is due to electrical MPI, since our simulation using the measured S21 didn't show BER floor. In real implementation, the length between reflection points is shorter compared with that in current setup, and can be more easily compensated by DSP.**
- **When 21GHz Tx BW (*cole_01_0914_smf.pdf*) rather than 16GHz Tx BW is used, the requirement on tap number is further reduced.**

- **21GHz Tx BW, and 5 tap FFE + 1 tap DFE in Rx EQ is recommended**

Possible Wavelength Assignment

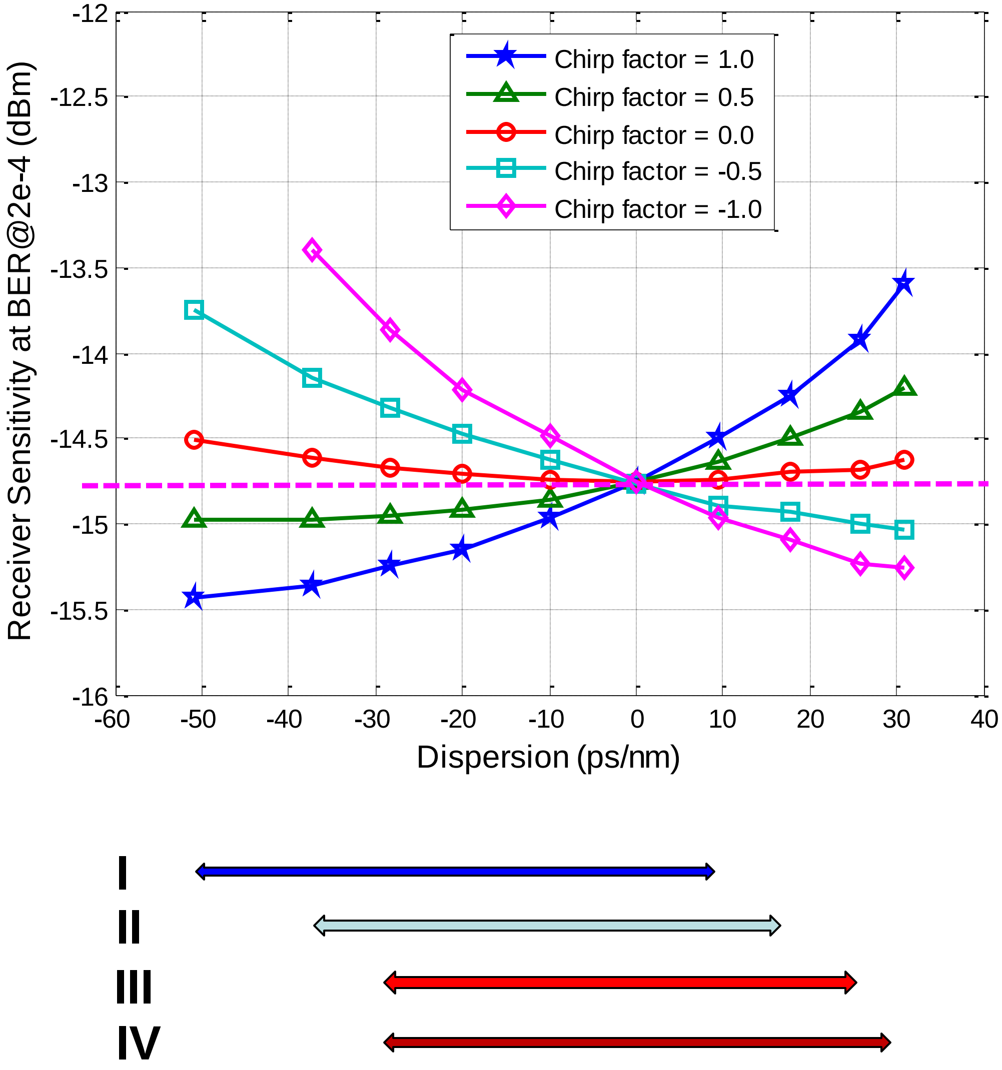
Index	Assignment schemes	Central Wavelength (nm)	Min/Max Wavelength (nm)	10km dispersion range (ps/nm)
I	Blue-band extension with 10nm gap	1273.55, 1277.89 1282.26, 1286.66 1295.56, 1300.05 1304.58, 1309.14	1272.55 /1310.19	-50 .8~ +9.4
II	Symmetric extension	1286.66, 1291.10 1295.56, 1300.05 1304.58, 1309.14 1313.73, 1318.35	1285.65 /1319.42	-37.3 ~ +17.7
III	Red-band extension	1295.56, 1300.05 1304.58, 1309.14 1313.73, 1318.35 1323.01, 1327.69	1294.53 /1328.78	-28.4 ~ + 25.7
IV	Red-band extension with 10nm gap	1295.56, 1300.05 1304.58, 1309.14 1319.51, 1324.17 1328.87, 1333.60	1294.53 /1334.46	-28.4 ~ +31.0

A 10 nm gap allows use of dual 4-lane TOSA/ROSA with external optical Mux/DeMux for early adopters (*cole_3bs_01a_1114.pdf, shirao_3bs_01_1114.pdf*)

Simulation Conditions for Dispersion & Chirp Evaluation

Parameters	**Values**
Format	NRZ
Baud Rate	53.2 Gbaud/s
Pattern	SSPR
Modulator	Ideal intensity modulation
Tx BW	21GHz
Tx S21 shape	4^{th} order Bessel filter
Extinction ratio	6 dB
RIN	-140 dB/Hz
Rx BW	21GHz
Rx S21 shape	4^{th} order Bessel filter
Rx Responsivity	0.6 A/W
Rx input noise density	15 pA/sqrt(Hz)
Equalizer	5 tap FFE + 1 tap DFE

Dispersion Tolerance with Different Chirps



- **For chirp in the range of [-0.5~+1.0], simulated dispersion penalty less than 1.5dB for all evaluated wavelength assignment schemes**
- **Blue-band extension offers best performance with positive chirp**
- **Mach-Zehnder modulator exhibits close to zero chirp**
- **EML chirp is design and bias dependent, desirable chirp (or close zero chirp) can be achieved via design and adjusting bias voltage**

Link Budget in OMA

Applications	Duplex 2km	Duplex 10km
Number of wavelength	8	
Baud rate	53.2 GBaud/s	53.2 GBaud/s
Operating BER	2e-4	2e-4
ER	≥6dB	
Transmitter output OMA	1.0dBm	3.0dBm
Mux IL(1)	3dB	3dB
Fiber/connector loss (2)	5dB	6.4dB
MPI penalty (3)	0.2dB	0.2dB
Dispersion penalty	0.5dB	1.5dB
DeMux IL(1)	3dB	3dB
Post-DeMux Rx input OMA	-10.7dBm	-11.1dBm
Rx sensitivity (OMA)(4)	-12.6dBm	-12.6dBm
Margin	1.9 dB	1.5dB

Tx BW and Rx BW used are 16GHz and 22 GHz respectively, 9 tap FFE + 1 tap DFE in Rx EQ is used in this table

(1) cole_01_0914_smf.pdf ; (2) kolesar_3bs_01_0514.pdf;

(3) wen_3bs_01_0914.pdf, at 30dB MPI

(4) The receiver sensitivity was measured in average power and has been converted to OMA

Comparison of Current Scheme with that of wen_3bs_01_0914.pdf

Parameters	**wen_3bs_01_0914.pdf**	**Current work**
Technical scheme	**Using high BW Tx with no equalization in Rx**	**Using low BW Tx and Rx with equalization in Rx**
Transmitter	Mitsubishi 43G EML	LR4 28G EML TOSA
Baud rate	56 GBaud/s	56 GBaud/s
Format	NRZ	NRZ
Tx 3dB BW (including driver)	36GHz	16GHz
ER	10.4dB	6.0dB
Receiver (PIN+TIA) 3dB BW	35GHz BW (U2t receiver)	22GHz BW (Discovery R401HG)
Equalizer in Rx	No	5-tap FFE + 1 tap DFE
BtB Rx Sensitivity in average optical power (BER@2e-4)	-13.9dBm	-12.5dBm
Meet link budget with margin	Yes	Yes

Summary

- Demonstrated the feasibility of 8x56G NRZ for 400GbE 2km and 10km PMD using mature100G (4x28G) optics, with RX equalization using 5-tap FFE+ 1-tap DFE;
- Demonstrated sufficient link budget for both 2km and 10km (with 1.5dB extra margin) 400GbE applications;
- Demonstrated via simulation that 1.5dB dispersion penalty allocation is sufficient for EMLs of either negative or positive chirp factor within -0.5~+1.0