Experimental Demonstration of 56Gbps NRZ for 400GbE 2km and 10km PMD Using 28Gbps Optical Transmitter and 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:

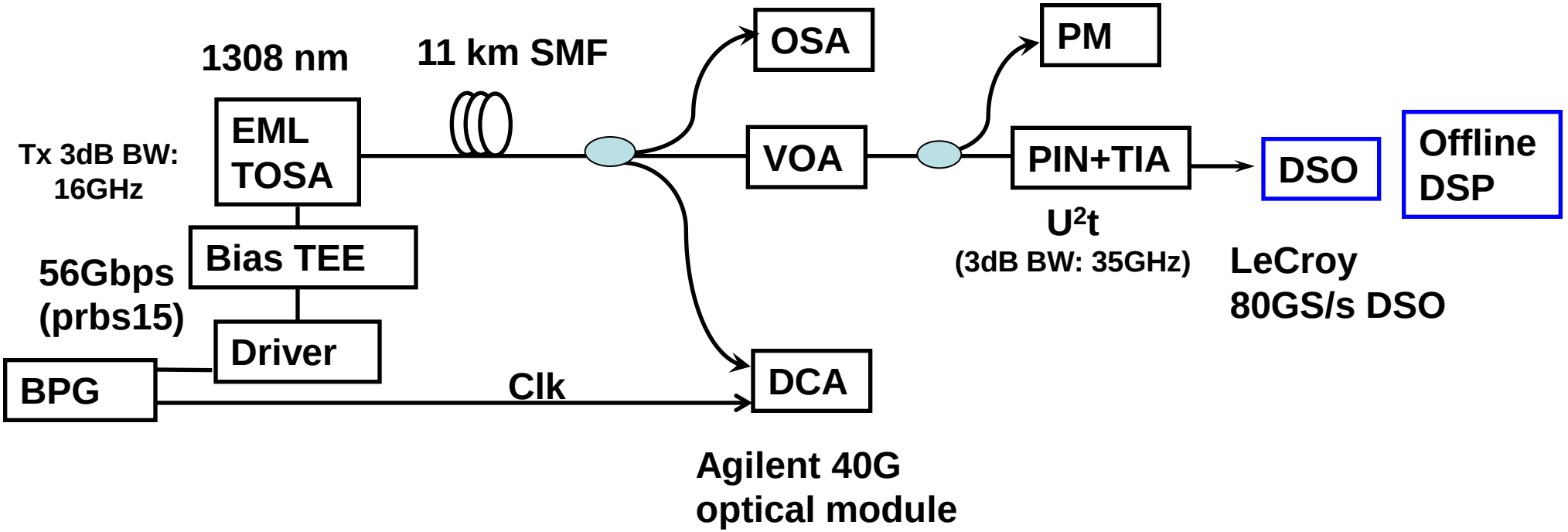
  cole_01_0914_smf.pdf; qian_3bs_01_0714.pdf; zhu_3bs_01a_0514.pdf; zhu_3bs_01_0714.pdf; shirao_3bs_01a_0714.pdf; stassar_01_1014_smf.pdf

- In *wen_3bs_01_1114.pdf*, we demonstrated 56Gbps NRZ for 400GbE PMD using SerDes for electrical 56Gbps NRZ generation, which shows the feasibility of 50G electrical I/O.
- In September Interim Meeting, we demonstrated optical 56Gbps NRZ operation using commercially available 43G optical transmitter and receiver for 400GbE PMD (*wen_3bs_01_0914.pdf*).
- It is desirable to explore the possibility of using Rx EQ to further reduce the optical transmitter bandwidth requirement, in order to reuse the current 100G (4x28Gbps) optics.

Work in this Presentation

- In this presentation, we
  - Demonstrate 56Gbps NRZ for 400GbE PMD using 28G optical transmitter and Rx equalizer
  - Analyze optical link budget for 400GbE 2km and 10km PMD
  - Compare Tx BW dependence between 56Gbps NRZ and 56Gbps PAM4
  - Analyze wavelength assignment for 8 wavelength LAN-WDM

Experimental Setup



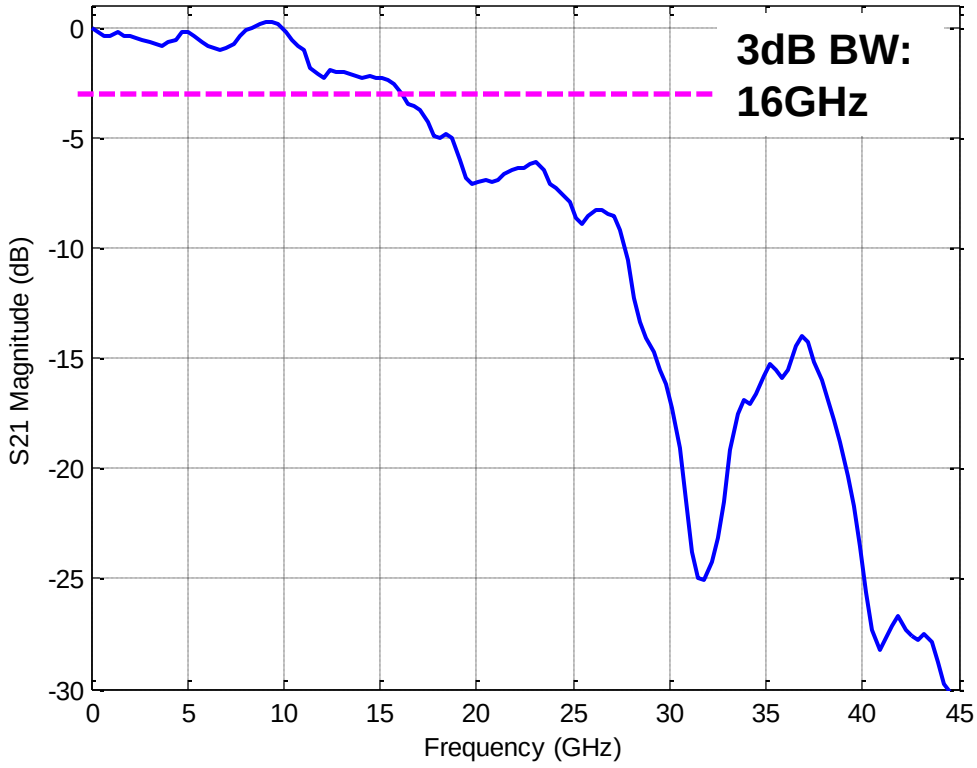
- **Operation conditions of EML:**
  - **Laser bias current = 80mA**
  - **Operating temperature: 40 deg C**

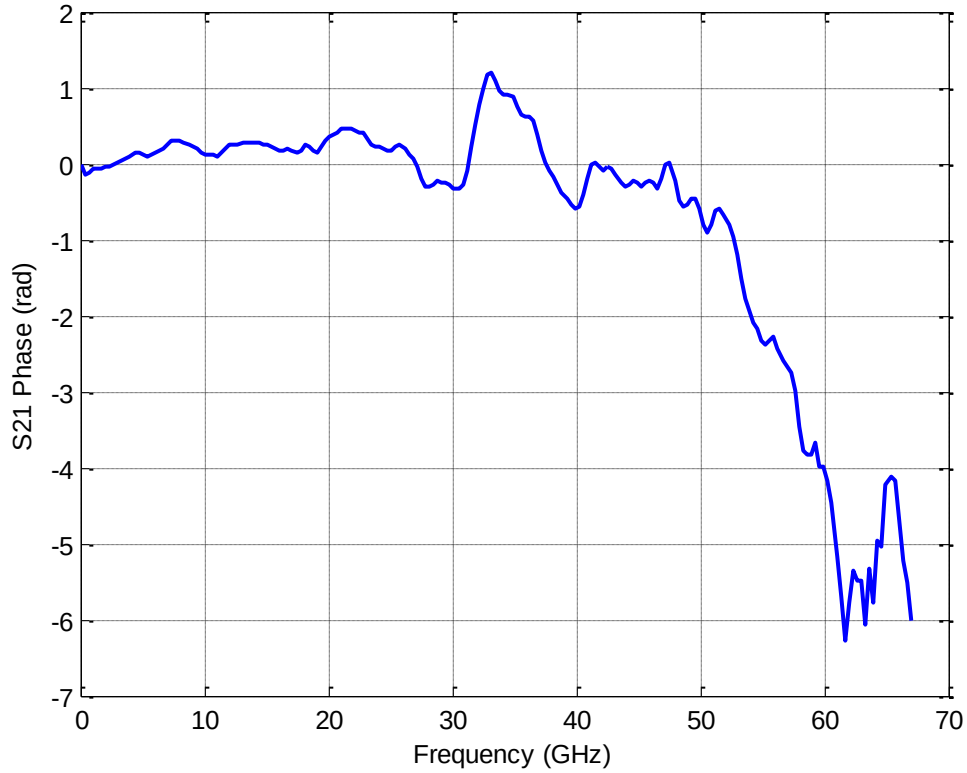
- **Equalizer: FFE or FFE+DFE**
- **FFE and DFE could be done in analog domain without using A/D conversion**

In *wen_3bs_01_1114.pdf*, we have shown there is no performance difference between prbs31 and prbs15 for NRZ

S21 of the transmitter under test

Driver +Bias Tee+ EML

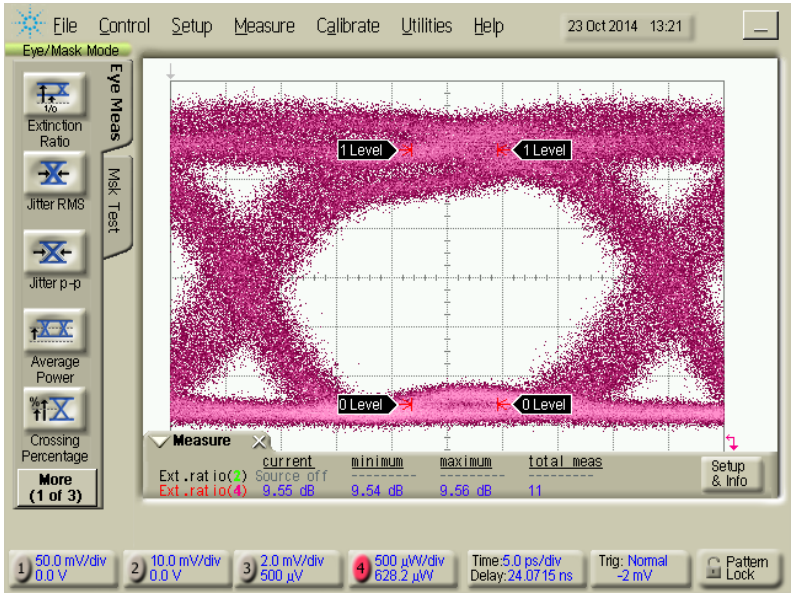




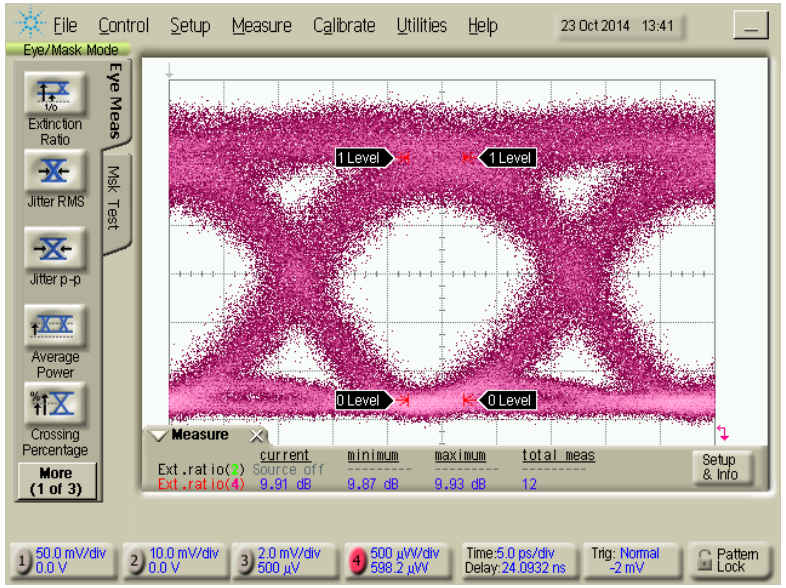
Dip in response due to packaging

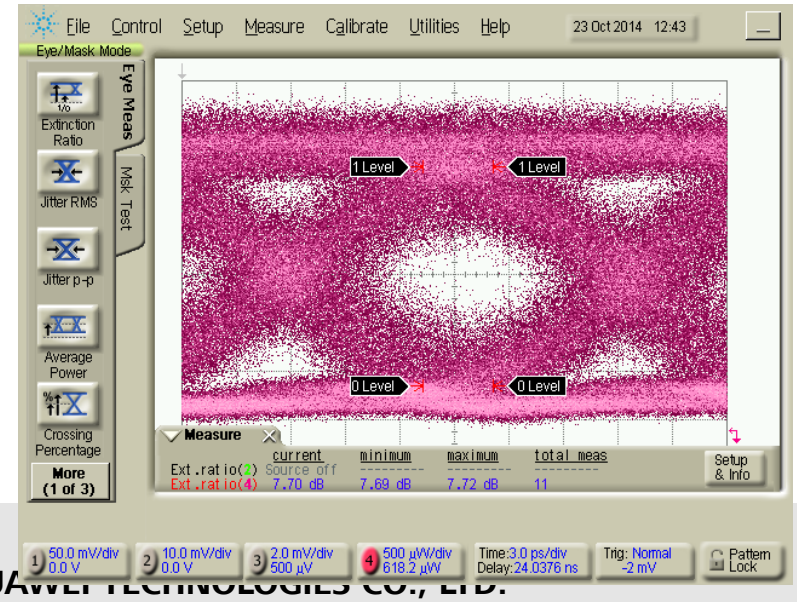
Eye Diagrams

28Gbps



40Gbps

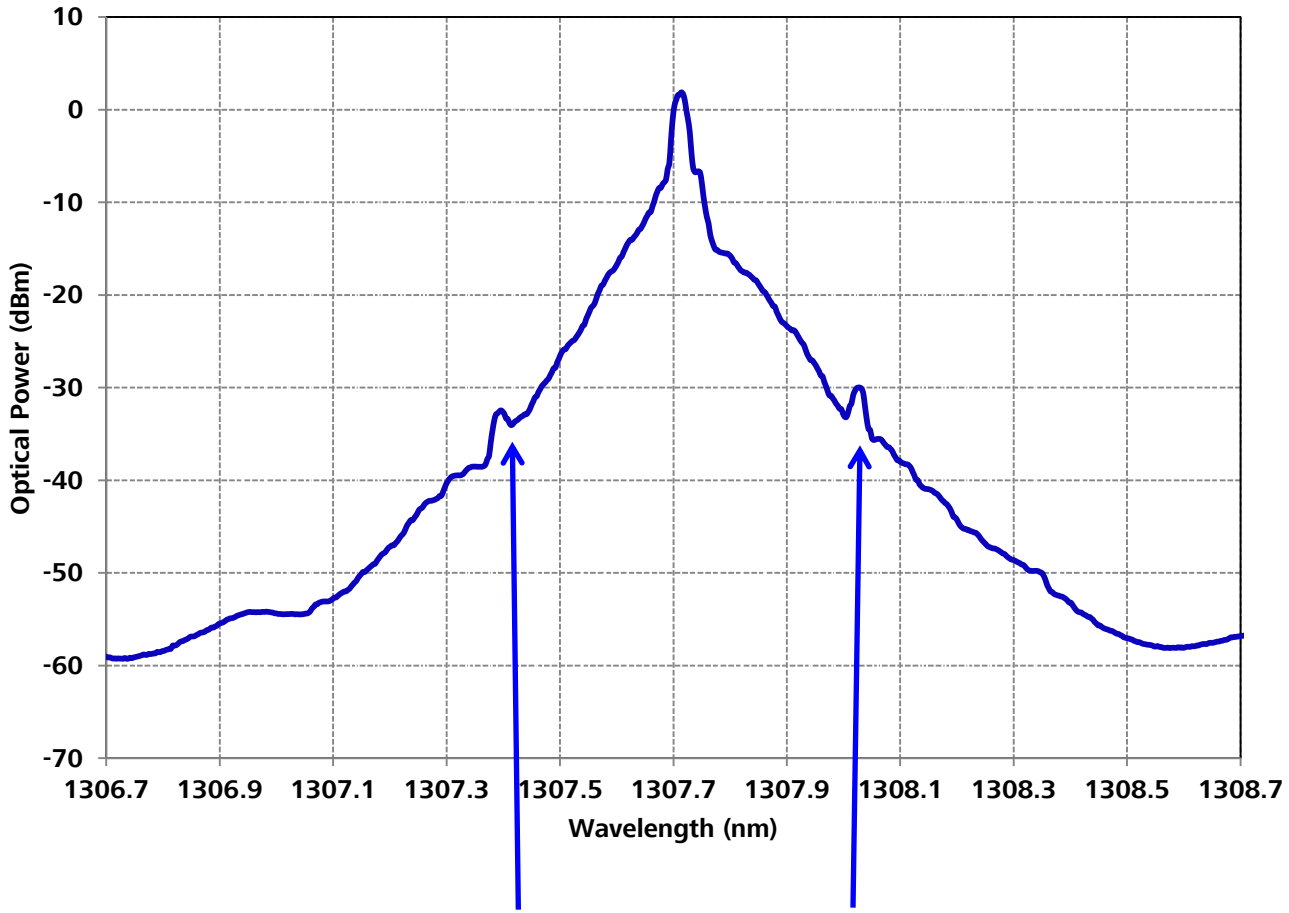




56Gbps

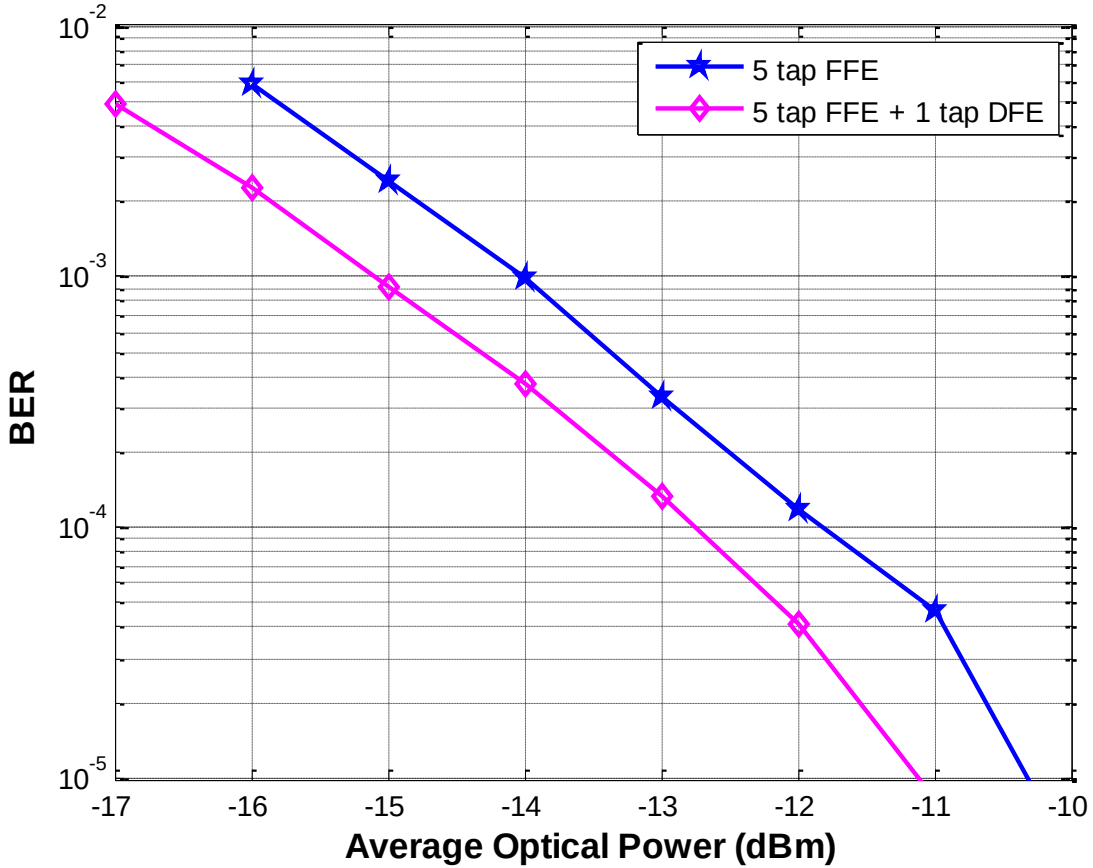
- **Blurry optical eye observed for 56 Gbps data rate is due to transmitter band limitation**
- **ER = 7.7dB**

Optical Spectrum



- **Red sideband enhanced in optical spectrum, indicating negative frequency chirping**
- **Different from that in *wen_3bs_01_0914.pdf & wen_3bs_01_1114.pdf*, where Mitsubishi 43G EMLs were tested and positive chirp were observed.**

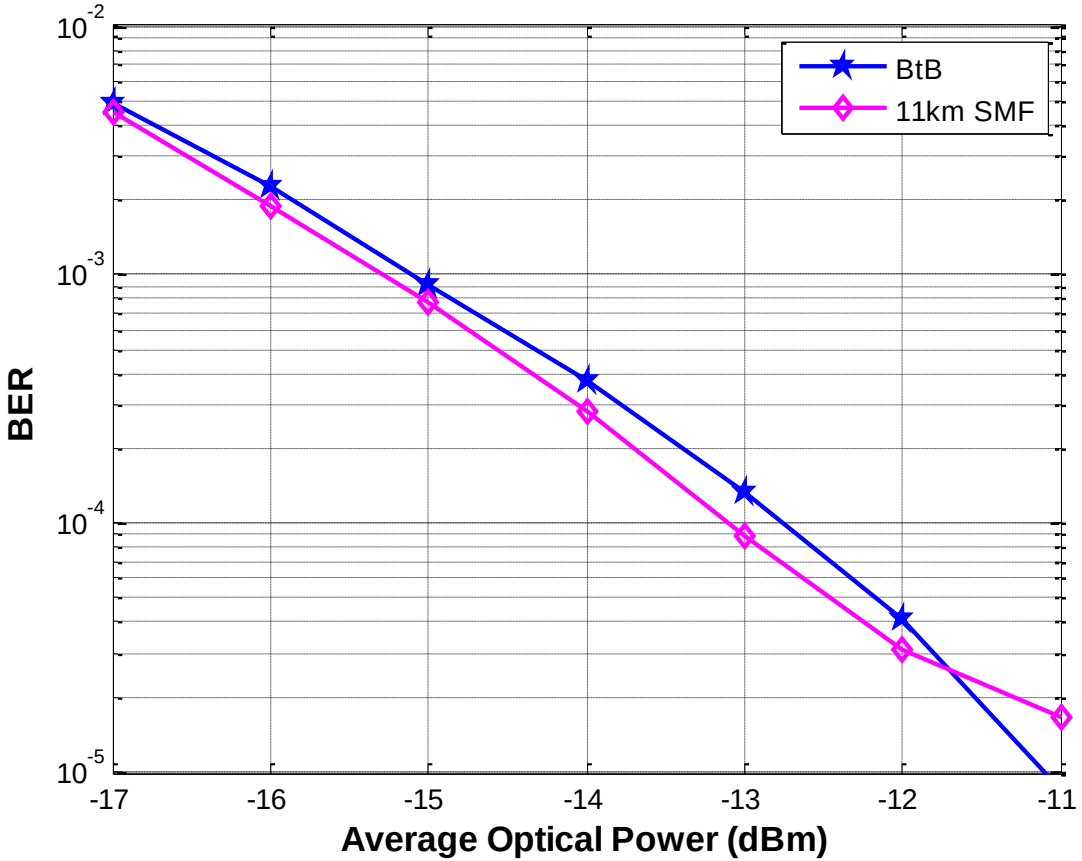
BER vs Average Optical Power



- **Back-to-back**
- **ER ~ 7.7dB**

- **With 5 tap FFE equalizer in Rx, the receiver sensitivity is -14 dBm at BER@1e-3;**
- **With 5 tap FFE+1 tap DFE, the receiver sensitivity is -15.1 dBm at BER@1e-3 and -13.4 dBm at BER@2e-4**

Transmission Performance



- **ER = 7.7dB**
- **5 tap FFE +1 tap DFE**

- **After 11km SMF transmission, 0.2dB negative penalty at BER@1e-3 is observed due to negative chirping of the EML;**

Link Budget in OMA

Applications	Duplex 2km	Duplex 10km
Number of wavelength	8	
Baud rate	53.2 GBaud/s	56 GBaud/s
Operating BER	2e-4	1e-3
ER	≥6dB	
Transmitter output OMA	3.0dBm	3.0dBm
Mux IL(1)	3dB	3dB
Fiber/connector loss and MPI (2)	5dB	6.4dB
MPI penalty (3)	0.2dB	0.2dB
Dispersion penalty	1.0dB	1.5dB
DeMux IL(1)	3dB	3dB
Post-DeMux Rx input OMA	-9.2dBm	-11.1dBm
Rx sensitivity (OMA)(4)	-11.4dBm	-12.9dBm
Margin	2.2dB	1.8dB

(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 at 56Gbps with ER=7.7dB, and has been converted to OMA with ER=6dB for 56Gpbs and 53.2Gbps respectively

Comparison of Current Scheme with that of wen_3bs_01_0914.pdf

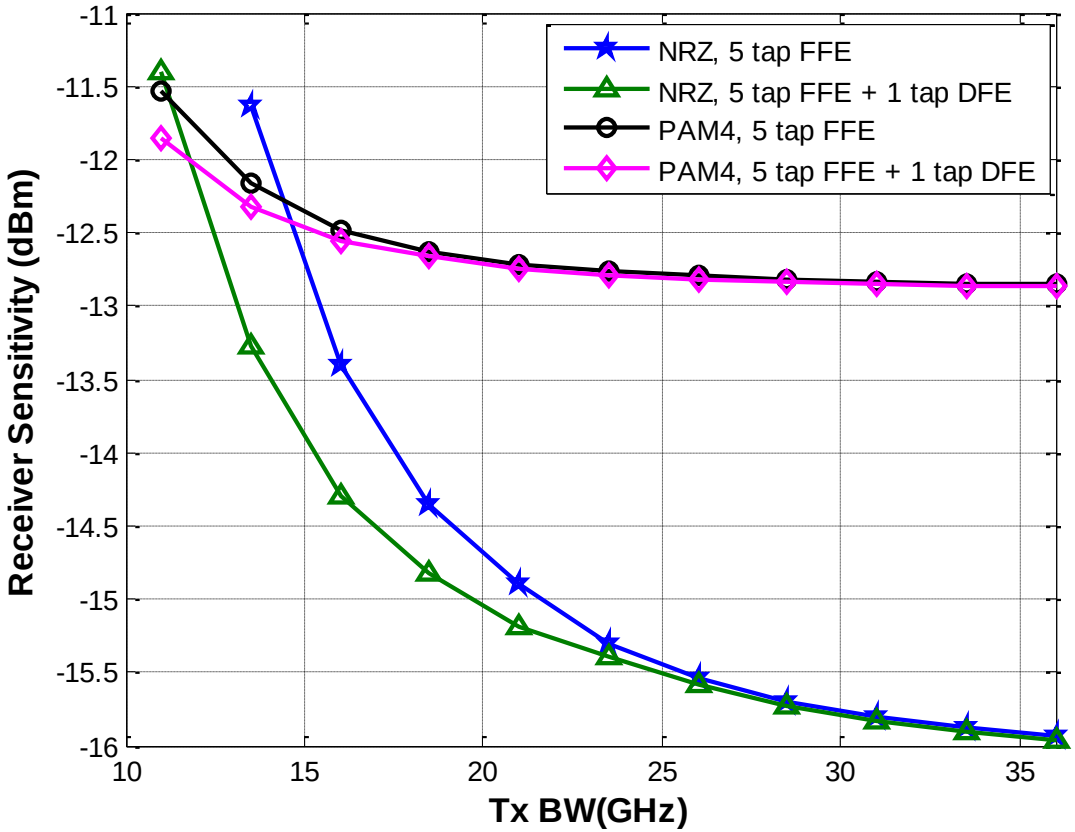
Parameters	wen_3bs_01_0914.pdf	Current work
Technical scheme	**Using high BW Tx with no equalization in Rx**	**Using low BW Tx with equalization in Rx**
Transmitter	Mitsubishi 43G EML	LR4 28G EML TOSA
Baud rate	56 GBaud/s	56 GBaud/s
Format	NRZ	NRZ
Tx 3dB BW (including driver)	36GHz	16GHz
ER	10.4dB	7.7dB
Frequency chirp	positive	negative
Receiver	U2t receiver (35GHz BW)	U2t receiver (35GHz BW)
Equalizer in Rx	No	5 tap FFE + 1 tap DFE
BtB Rx Sensitivity in average optical power (BER@1e-3)	-14.8dBm(1)	-15.1dBm
Meet link budget with margin	Yes	Yes

(1) No CDR used

Comparison on Tx BW Requirement between NRZ and PAM4 – Simulation conditions

Parameters	**Values**	
	NRZ	PAM4
Bit rate	56 Gbps	56 Gbps
Baud Rate	56 Gbaud/s	28 Gbaud/s
Format	NRZ	PAM4
Modulator	Ideal intensity modulation	
Tx BW	Varied	
Tx S21 shape	4^{th} order Bessel filter	
Extinction ratio	6 dB	
RIN	-140 dB/Hz	
Rx BW	28GHz	21GHz
Rx S21 shape	4^{th} order Bessel filter	
Rx Responsivity	0.6 A/W	
Rx noise density	15 pA/sqrt(Hz)	

Comparison on Tx BW Dependence between 56Gbps NRZ and 56Gbps PAM4 - Result



- The receiver sensitivity is defined at BER@1e-3

- **With only 5 tap FFE equalizer, NRZ has better sensitivity for Tx BW ≥15GHz**
- **With 5 tap FFE + 1 tap DFE, NRZ has better sensitivity than PAM4 for Tx BW ≥ 13GHz**
- **At 16GHz Tx BW, 56Gbaud NRZ 's sensitivity is 1.7dB better than that of 28Gbaud PAM4, carrying the same data rate of 56Gbps.**

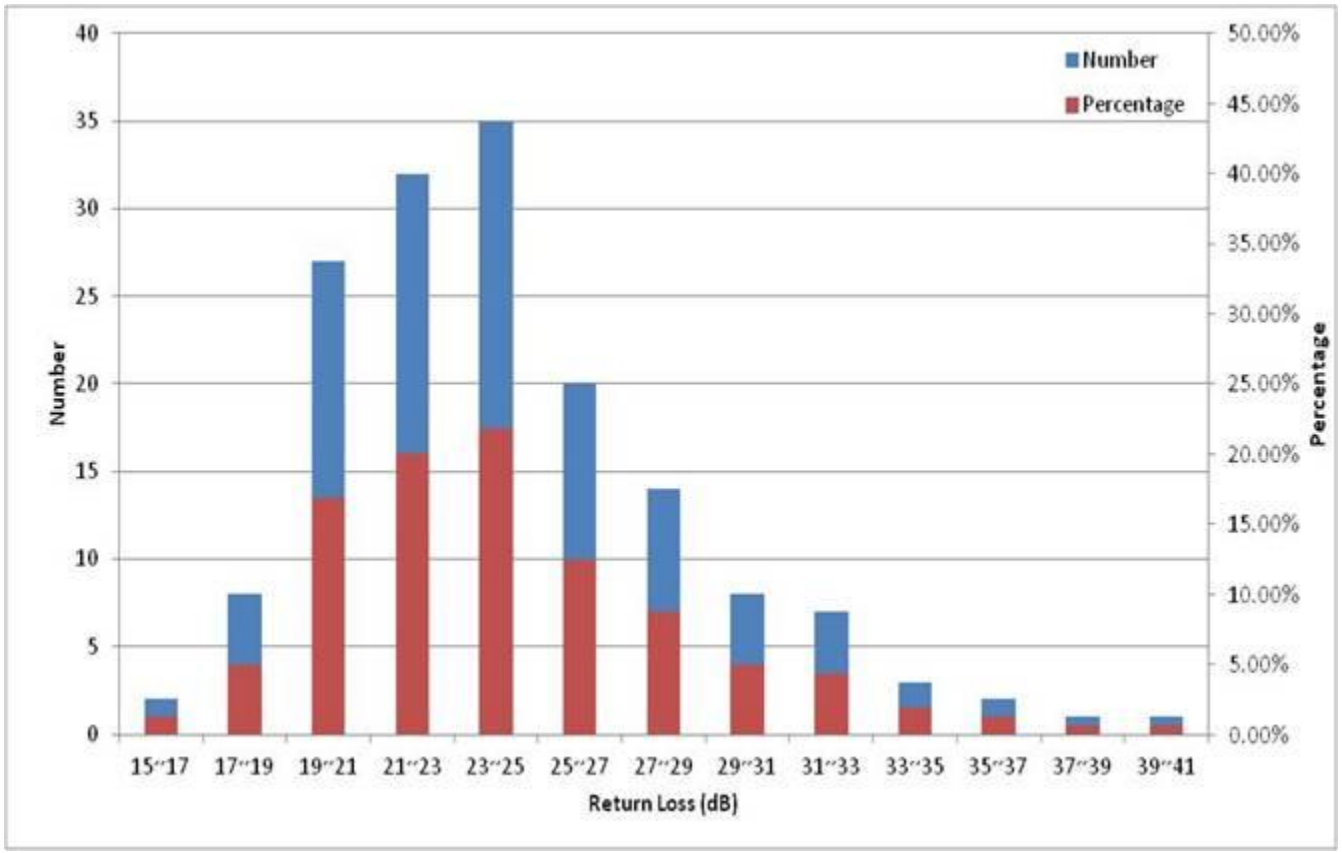
How Much MPI We Need to Consider

- *wen_3bs_01_0914.pdf* and this contribution considered 30dB MPI
- nicholl_3bs_01_1114.pdf suggested 37dB MPI by increasing the requirement of TX reflectance
- Fiber connector return loss of 26dB (or 35dB) are all manufacturer specs
- Real connector reflection and MPI is determined by how dirty the connectors are
- In data center, connector reflection can easily go to below 20dB
- Typical min adjacent channel isolation of LAN-WDM DeMux is around 25dB(1)
  - The middle channels may suffer from 22dB crosstalk under worst case
- What we can do:
  - Take the risk that the bad situation is not going to happen
  - Well train operation staff to well clean each connector, and

    Push DeMux vendors to increase channel isolation without increasing IL
  - Leave certain margin for MPI penalty
- 30dB MPI is a relatively conservative number

(1) http://www.cubeoptics.com/uploads/tx_cuboproducts/C-40_SM_LAN_RS_Rev.12_COLOR_CUBE_LAN-WDM_4_channel_reduced_size_02.pdf

Return Loss Distribution of Dirty Connectors



- Evaluation (with LC connectors) run for another project rather than 400GbE
- Emulating dirty connectors by introducing oil and dust to the connectors
- Return loss of dirty connectors varies from 15dB to 41dB
- Most of return loss in the range of 19dB~29dB

Wavelength Assignment – Symmetric Extension

Lane	Central Frequency (THz)	Central Wavelength (nm)	Wavelength range (nm)
L_0	233.0	1286.66	1285.65~1287.68
L_1	232.2	1291.10	1290.07~1292.12
L_2	231.4	1295.56	1294.53~1296.59
L_3	230.6	1300.05	1299.02~1301.09
L_4	229.8	1304.58	1303.54~1305.63
L_5	229.0	1309.14	1308.09~1310.19
L_6	228.2	1313.73	1312.67~1314.79
L_7	227.4	1318.35	1317.29~1319.42

Current 4-ch LAN-WDM

Recaptured from *wen_3bs_01_0914.pdf*

For 10km SMF:

- Max positive dispersion: +17.7 ps/nm
- Min Negative dispersion: -37.3 ps/nm

Relatively large amount of min negative dispersion than max positive dispersion, favors positive frequency chirping

Wavelength Assignment – Blue Band Extension

Lane	Center frequency (THz)	Center wavelength (nm)	Wavelength range (nm)
L_0	235.6	1272.46 nm	1271.47~1273.46
L_1	234.8	1276.80 nm	1275.80~1277.80
L_2	234 .0	1281.16 nm	1280.16~1282.17
L_3	233.2	1285.56 nm	1284.55~1286.57
L_4	231.4	1295.56 nm	1294.53~1296.59
L_5	230.6	1300.05 nm	1299.02~1301.09
L_6	229.8	1304.58 nm	1303.54~1305.63
L_7	229.0	1309.14 nm	1308.09~1310.19

Current 4-ch LAN-WDM

10nm gap

For 10km SMF:

- Max positive dispersion: +9.4 ps/nm
- Min negative dispersion: -52.0 ps/nm

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

Too large amount of min negative dispersion, strongly favors positive frequency chirping, not desirable for negative chirping and zero chirping

Wavelength Assignment – Red Band Extension

Current 4-ch LAN-WDM

Lane	Central Frequency (THz)	Central Wavelength (nm)	Wavelength range (nm)
L_0	231.4	1295.56	1294.53 to 1296.59
L_1	230.6	1300.05	1299.01 to 1301.09
L_2	229.8	1304.58	1303.53 to 1305.63
L_3	229.0	1309.14	1308.09 to 1310.19
L_4	227.2	1319.51	1318.44 to 1320.58
L_5	226.4	1324.17	1323.10 to 1325.25
L_6	225.6	1328.87	1327.78 to 1329.95
L_7	224.8	1333.60	1332.51 to 1334.69

10nm gap

For 10km SMF:

- Max positive dispersion: +31 ps/nm
- Min Negative dispersion: -28.4 ps/nm

Close amount between min negative dispersion and max positive dispersion, good for negative chirping, positive chirping, as well as zero chirping.

Summary

- Demonstrated the feasibility of 8x56G NRZ for 400GbE 2km and 10km PMD using 100G (4x28G) optical TX and RX EQ
- Demonstrated sufficient link budget for both 2km and 10km (with 1.8dB extra margin) 400GbE applications
- 56Gbaud NRZ has better sensitivity than 28Gbaud PAM4 even when using BW limited TX (3dB BW ~16 GHz)
- Analyzed impact of wavelength assignment on laser chirping, and more laser chirping data is needed before decision