Innovative R&D by NTT

Technology comparison matrix for duplex SMF PMDs

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Overview

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■Motivation

Propose a baseline criteria of the technology selection for 400GE SMF PMDs considering possible technology advances.

■Previous presentation (recap.) (sone_3bs_01_0714)

Raised a question about a comparison using test equipment that would not be implemented in a commercial transceiver.

■Two main topics of this presentation

- **Transmission experiment results**

  Compare PAM4 and DMT on the same condition using DAC and ADC that can be implemented in a transceiver in a few years.

- **Comparison matrix and investigation items**
  - Make a comparison matrix of PAM4 and DMT considering performance, cost , size (power consumption)
  - Call for cooperation to complete our half-completed matrix. We need some data from participants associated with commercial production.

Comparison approach in transmission experiment

Experimental configuration must be realistic; i.e. can be implemented as commercial transceiver. PAM4 and DMT evaluated under the same condition by changing the following characteristics.
(1) Analog bandwidth of Tx optics
(2) Bitrate/λ (assumption for the number of lanes)
(3) The number of equalizer taps (only for PAM4)

Variations of experimental configuration

Low end

High end/
lab equipment

LSI(Tx)	Optics(Tx)
DAC	Laser + Mod.
DAC BW = 15 GHz	Common DML for 100GE
Wide Bandwidth DAC	Wide Bandwidth DML
	Common EML for 100GE
	Wide Bandwidth EML
Analog based Signal Generations	Wide Bandwidth MZ

Num. lanes
4 lane
8 lane

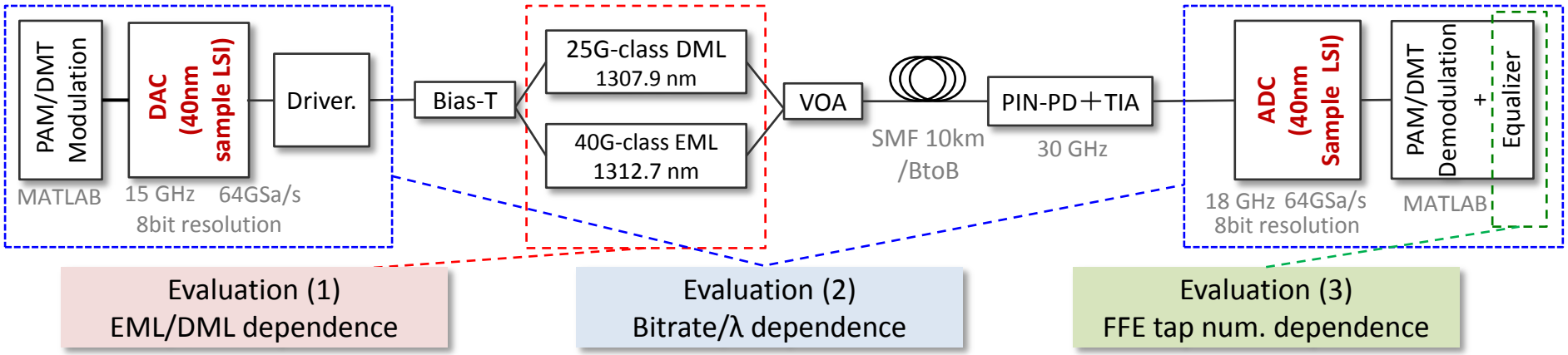
Optics(Rx)		LSI(Rx)	
Detector	TIA	ADC	Equalizer
PD	Narrow band Fixed Gain	ADC BW = 18 GHz	No EQL
	Narrow band AGC		5 taps
APD	Wide band Fixed gain		
	Wide band AGC	DSO BW = 32 GHz	

Configuration in this experiment

Only PAM4

We assume the DAC and ADC that can be implemented in transceivers in a few years.

Experimental configuration of PAM4 and DMT transmission



- Transmission setup is common other than signal generation.
- To evaluate the dependence on bandwidth, Tx device (EML/DML) is changed.
- Commercially available evaluation board LSI (40nm) is used.

Evalution		Modulation format	FFE TAP	Tx optics
Evaluation (1) (slide 4)	BER dependence on the analog bandwidth of Tx optics	116G-DMT (for 4λ)	15tap	**DML and EML**
		56G-PAM4 (for 8λ)		
Evaluation (2) (slide 5)	BER dependence on Bitrate/λ	**116G**-DMT (for 4λ)	15tap	DML
		112G-PAM4 (for 4λ)		
		58G-DMT (for 8λ)		
		56G-PAM4 (for 8λ)		
Evaluation (3) (slide 6)	BER dependence on number of equalization taps	56G-PAM4 (for 8λ)	**3tap – 25tap**	DML and EML

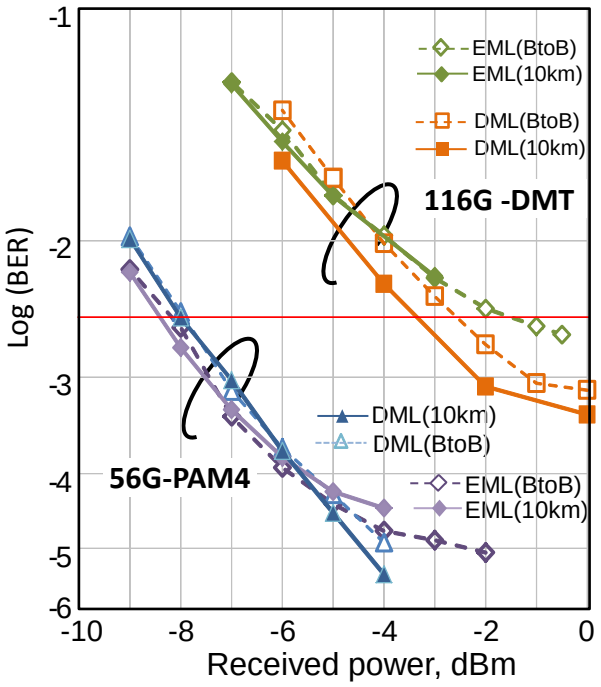
Evaluation result (1): Analog bandwidth dependence on BER

■BER is measured for 116G-DMT and 56G-PAM4 using EML and DML with different bandwidths

- Tx analog bandwidth (EML/DML) has a small impact with the DAC and ADC we used

DAC and ADC bandwidth is the bottleneck of analog bandwidth. They also limit the overall performance.

BER measurement result



Loss budget (7%OH-FEC) --> 10km SMF PMD needs 6.3dB

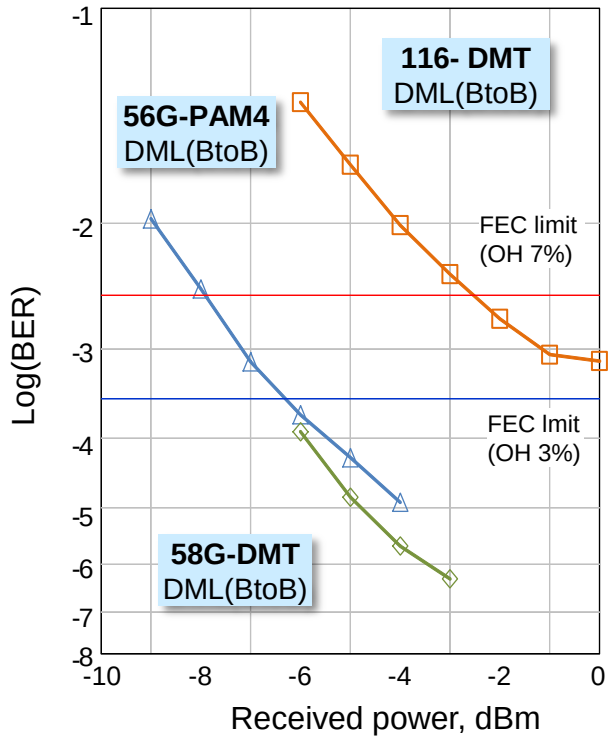
	116G-DMT		56G-PAM4	
	EML (40G-Class)	DML (25G-Class)	EML (40G-Class)	DML (25G-Class)
Tx output power (dBm)	0.45	10.2	1.1	10.2
Mux loss(dB)	2.5 *1		3.5 *1	
Demux loss(dB)	2.5 *1		3.6 *1	
Min. receiver sensitivity (dBm)	**-1**	**-3.5**	**-8**	**-8**
Loss budget(dB)	*No budget*	8.7	2.0 Not enough for 10km	11.1

*1 From cole_02_0814_smf

Evaluation result (2): BER dependence on bitrate/λ

■ BER of 116G-DMT, 112G-PAM4, 58G-DMT, and 56G-PAM4 are evaluated
- Loss budget : “58G-DMT” ≒ “56G-PAM4” > “116G-DMT”
  (112G-PAM4 is not feasible for 10km transmission)

BER measurement result



Loss budget (7% OH-FEC) -->10km SMF PMD needs 6.3dB

	For 4λ		For 8λ	
	116G-DMT	112G-PAM4	58G-DMT	56G-PAM4
Tx output (dBm)	10.2			
Mux loss (db)	2.5		3.5	
Demux loss (dB)	2.5		3.6	
Min. receiver sensitivity (dBm)	-2.5	NG	-8 .5	-8
Loss budget(dB)	**7.7**	**NG**	**11.6**	**11.1**

We were not able to transmit 116G-PAM4 signal even with “35tap FFE plus 35tap DFE”.

Evaluation result (3):
BER dependence on FFE tap num.

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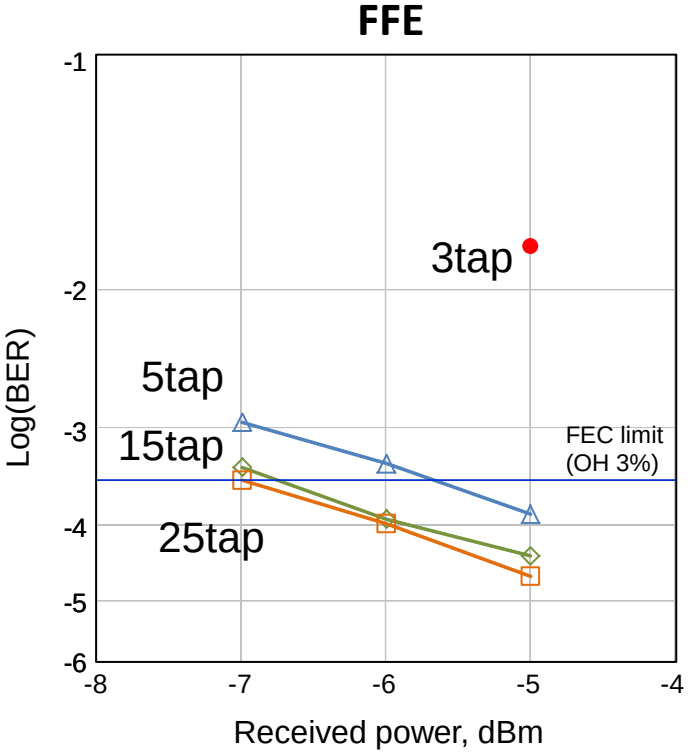
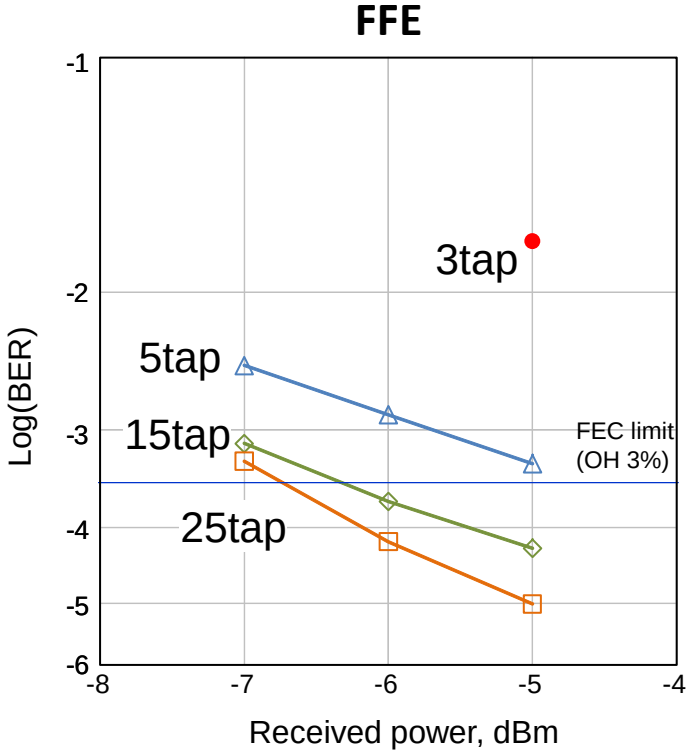
■BER dependence on equalization tap num. evaluated for 56G PAM4.
- 56G-PAM4 requires at least 5tap FFE.
- 15tap FFE is better (1 dB to 1.5 dB) than 5tap FFE.

56G-PAM4 EML (BtoB)



56G-PAM4 DML (BtoB)



Comparison premise in accordance with evaluation results

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Comparison of PAM4 and DMT must consider current DAC/ADC specification *1, since DAC/ADC is the performance limiter at this point.
We should exclude the option of 4λ PAM4 that is not feasible with current DAC/ADC performance.

*1 The best specification of DAC/ADC we assume (among commercially available Si circuit)
DAC : 15GHz, 64GSa/s, 8bit resolution
ADC : 18GHz, 64GSa/s, 8bit resolution

[The condition that achieves 10km transmission with current DAC/ADC]

Modulation format	Equalizer	FEC OH
4λ DMT (116G)	-	at least 7%
8λ DMT (58G)	-	at least 3%
8λ PAM4 (56G)	at least 5_tap *2	at least 3%
4λ PAM4 (112G)	NG even with “FFE 35tap + DFE 35tap”	

*2 15tap improves more 1dB

Technology comparison matrix for DMT and PAM4

Power consumption (size) winner
⇒ **Not clear.** **Need more investigations**

Performance (Loss budget) winner
⇒ **8λ PAM4/ 8λ DMT**
(penalty is under investigation)

Technology comparison matrix

		4λ DMT (116G)	8λ PAM4 (56G)	8λ DMT (58G)
Performance	Loss budget			
	Transmission penalty	**Need information**		
Power consumption (size)		FFT+ 7%OH-FEC 24W(2014) 12W(2016)*	FFE15tap + 3%OH-FEC **Need information**	FFT+ 3%OH-FEC **Need information**
Cost	Number of lanes	4 lanes 	8 lanes 	

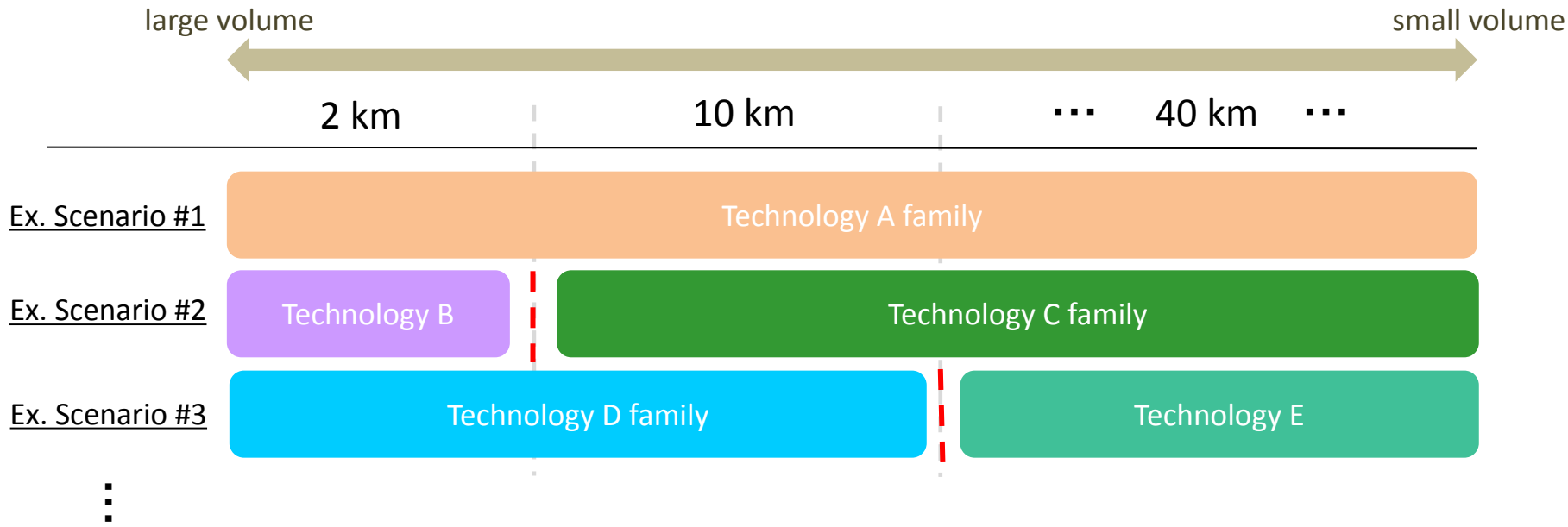
 good  acceptable

*from tanaka_400_01a_0913

Cost winner
⇒ **4λ DMT** : 25G-class DML is enough for both.
The number of lanes will the main cost determiner.

Potential of market expansion

Commonization of technologies including an extended reach interface (future generation) may expand the market potential of 1st generation PMDs. This may improve the overall cost advantage of 400GE.



The magnitude of cost advantage by technology commonization between 1st generation PMDs and future extended reach PMDs.

Scenario #1 > Scenario #2 > Scenario #3

Investigation items to complete technology comparison matrix

There are some items to investigate in order to complete the technology comparison matrix.

Cooperation would be appreciated from the parties /members associated with commercial production . → for (1) and (3)

	Investigation items
Performance	**(1) Transmission penalty:** Under investigation by technology proponents
	(2) Potential performance improvement FEC-OH and its power consumption could be reduced by using APD to increase loss budget
Power consumption (size)	**(3) Estimation of LSI power consumption.** Circuit size and power consumption for equalization in PAM4 and FFT in DMT
Cost	**(4) Extended reach technology** Clarify the candidate technologies for cover future need of extended reach in order to confirm whether technology can be shared
Potential of market expansion	

Summary

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■Experimental results

- DAC and ADC will limit performance considering production of transceivers for PAM4 and DMT.
- 4λ PAM4 is not feasible with current specification of DAC and DAC.

■Technology comparison matrix

- Practical DAC and ADC specification is the most important condition for performance comparison.
- Showed a half-completed technology comparison matrix.

■Future plans

- Complete technology comparison matrix by filling in the missing parts by clarifying the following items.
  - ・Performance improvement achieved by using APD
  - ・Candidate technology for extended reach interface
  - ・Transmission penalty and power consumption

→We need the cooperation by members associated with commercial production.