Status of silicon photonics link budget

Ichiro Ogura, PETRA
Richard Pitwon, AIO Core

IEEE 802.3cz Multi-Gigabit Optical Automotive Ethernet Task Force
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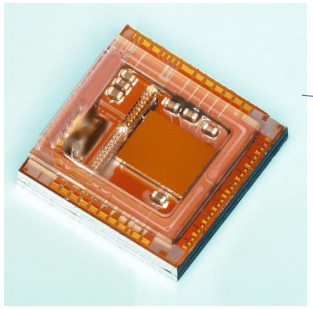
Summary

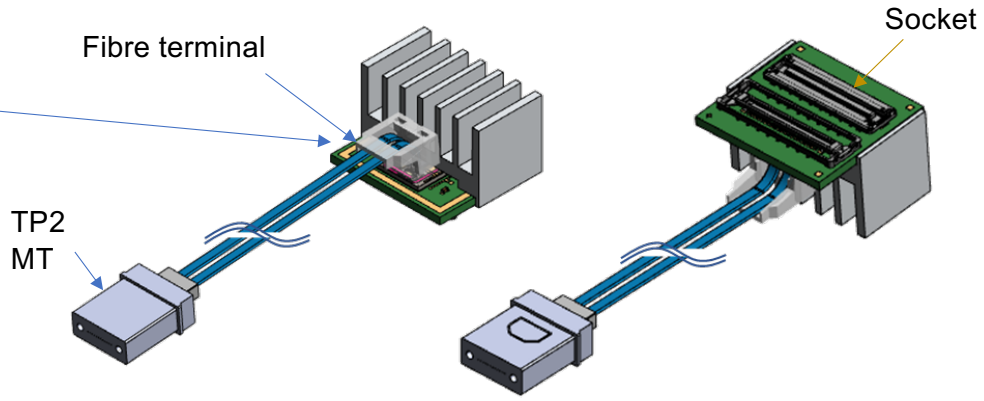
- Evaluation of links up to 125 ºC using commercially available Si-Ph optical transceiver
- Single channel link is evaluated as well as the VCSEL's link budget estimation
- BERs are measured back-to-back and over 40 m with 4 optical connector using OM3 fibre
- Transmission and receive specifications are proposed based on IEEE 802.3bm
- In order to determine the transmission specification for 40 m, it is suggested that the launch condition should be discussed in addition to the bandwidth of the fibre.

Evaluated sample

A commercial Si-Ph optical transceiver with integrated 4ch Tx and 4ch Rx is mounted on a small board, an EOM (Embedded Optical Module) with short MMFs, and electrical signals are connected to the board via sockets.

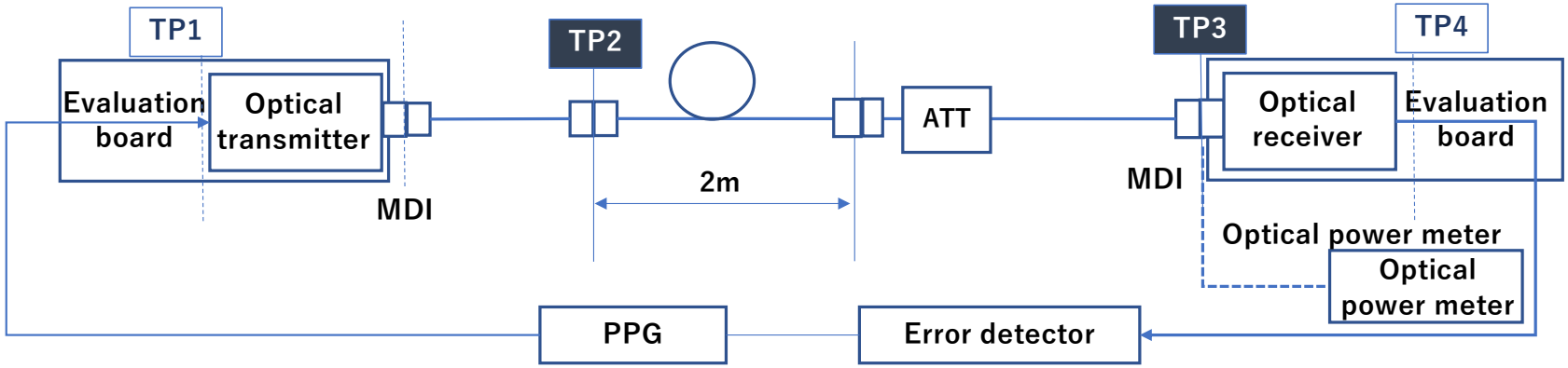


Si-Ph optical transceiver including
LD and IC of Tx and Rx

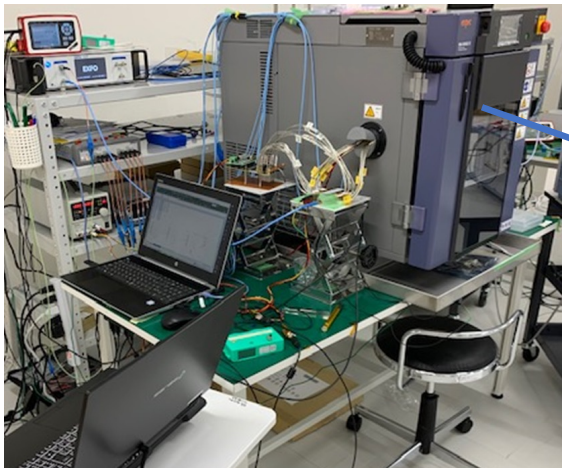


Although the performance of the evaluation data tends to be lower than the ideal data obtained by simulation, the evaluation data represents the value when actually used. This is because the actual evaluation includes noise and individual variations, which cannot be accurately reflected in the simulation.
The specifications should be decided based on the actual measured data in the module where it is worse than the simulation.

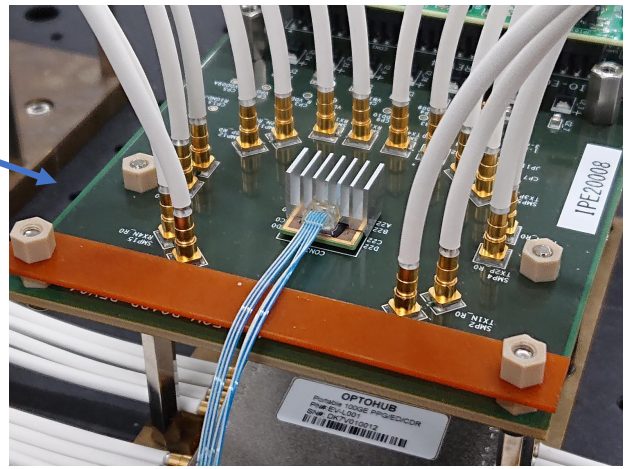
Link evaluation (back to back)



25G_SiPh_MMF measurement block diagram

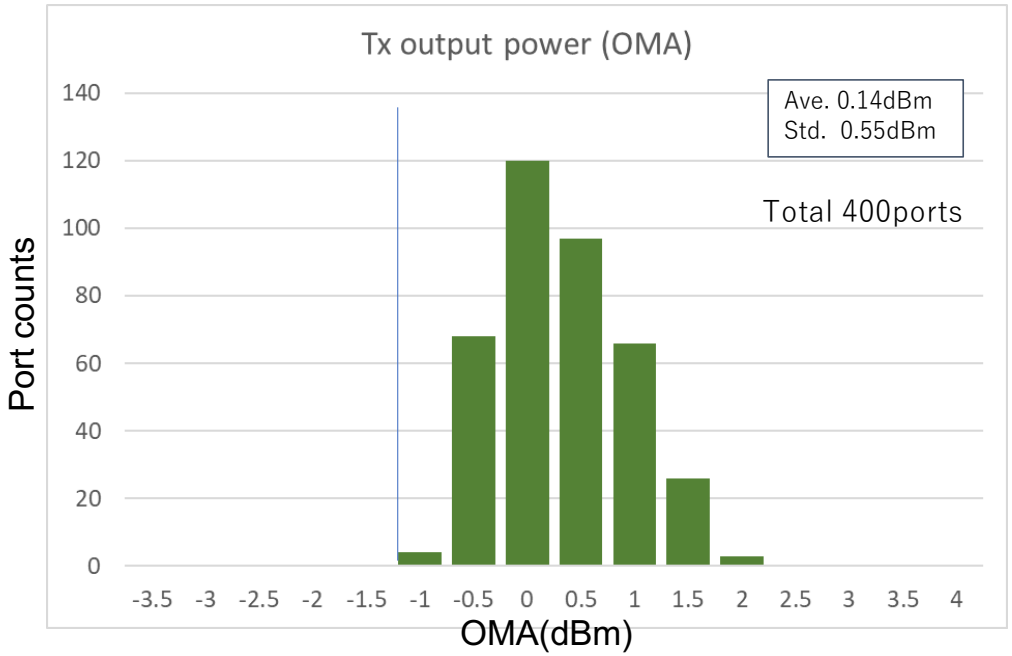


Test setup



EOM on a test board

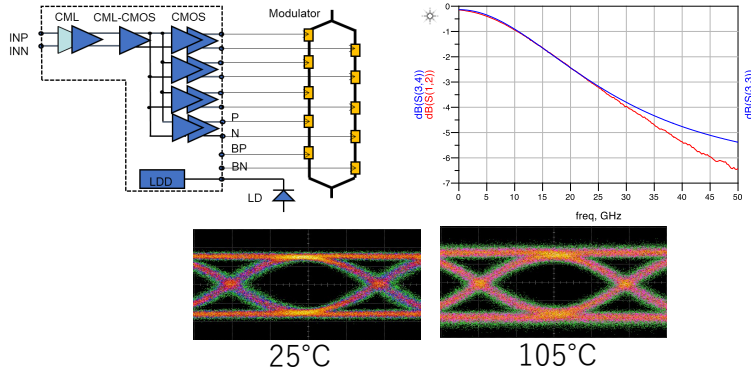
Output power (OMA) distribution at TP2



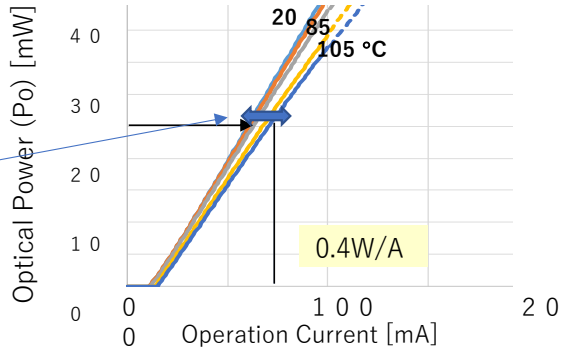
Tx output power (OMA)

In a normal test, the operation current is fixed at 75 mA and measured.
In actual use, the operation current can be adjusted to keep the OMA constant.

The Si-Ph Mach–Zehnder modulator features CMOS on/off operation and temperature independent frequency characteristics.
The optical output waveform can obtain a clear waveform with less jitter without using waveform shaping.

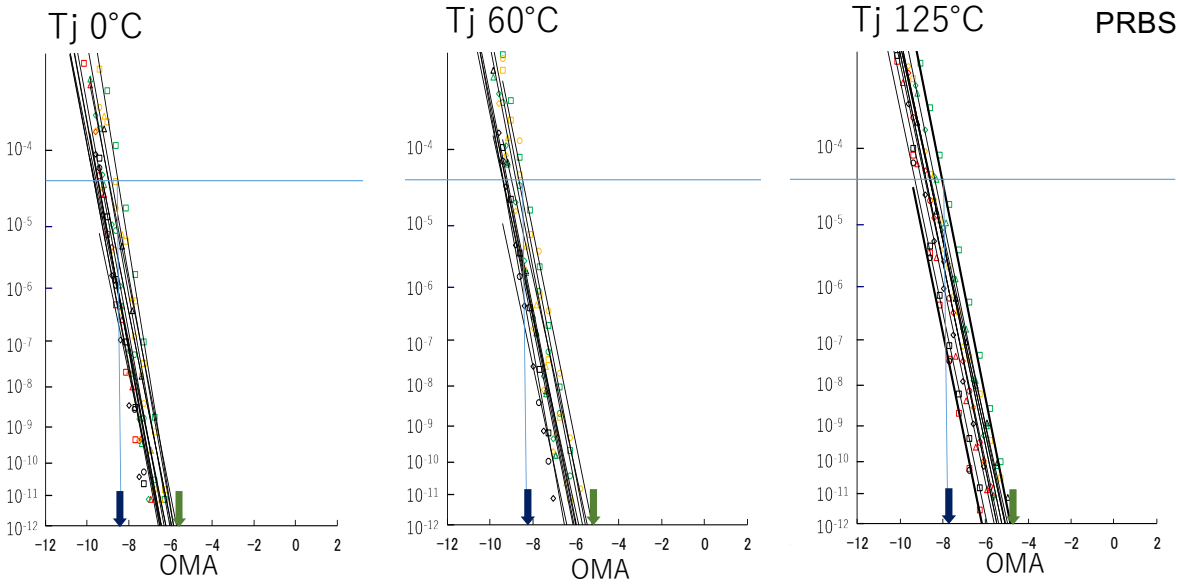


The operating current of the LD is variable to keep the constant light output.



Receiving power (OM3) at 25G at TP3

Receiving power (OM3)



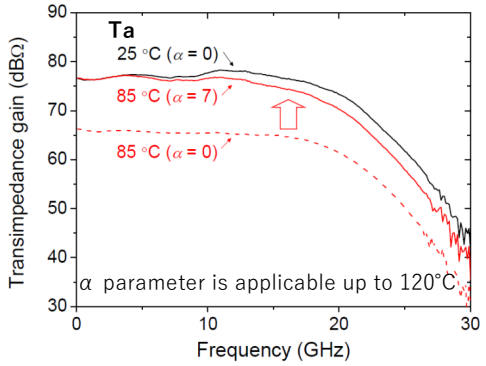
	Tj 0°C (Ta -20°C)	Tj 60°C (Ta 40°C)	Tj 125°C (Ta 105°C)
w/FEC	**-8.3 dBm**	**-8.2 dBm**	**-7.8 dBm**
w/o FEC	-5.8 dBm	-5.6 dBm	-5.0 dBm

Main specification Ge-PD on Si-Ph
Sensitivity: 0.5 A/W
Frequency response: 18 GHz

IC gain characteristics for frequency

The receiver IC has a gain adjustment function for high temperature operation.

α :gain adjustment parameter

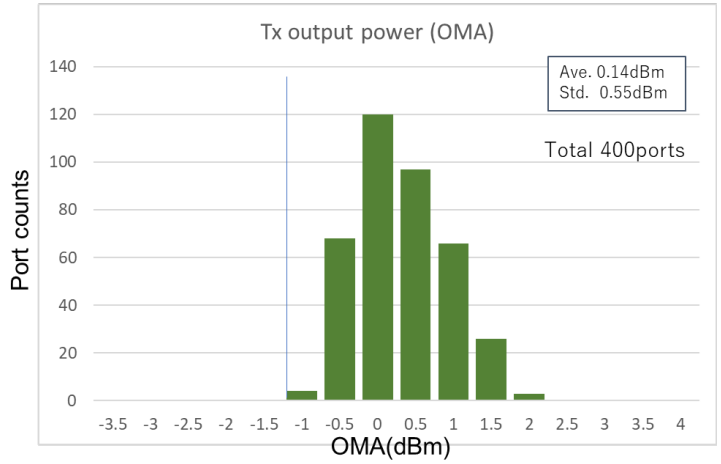


The Si-Ph transceiver does **not use CDR**.
The results include an electrical socket and evaluation board losses of approximately 10 dB.
It is estimated that the receiver sensitivity is improved by about 1.5 dB when using conventional InGaAs-PD instead of Ge-PD on Si-Ph.

Link budget

Link budget for 25 Gb/s PRBS^{31} at $T_{junction}$ = 125 ℃ and $T_{ambient}$ = 105 ℃ over OM3 fibre

- With FEC
  - 7.8 dB (average)
  - 6.8 dB (worst case)
- Without FEC
  - 5 dB (average)
  - 4 dB (worst case)



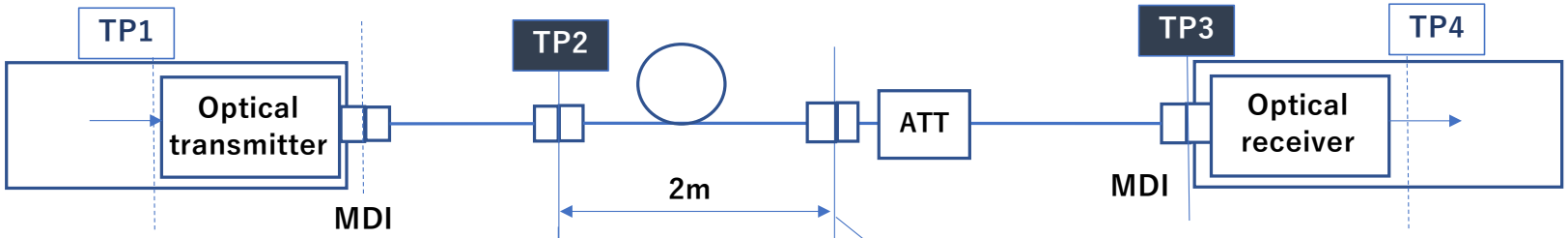
Tx output power (OMA)

	Tj 0°C (Ta -20°C)	Tj 60°C (Ta 40°C)	Tj 125°C (Ta 105°C)
w/FEC	**-8.3 dBm**	**-8.2 dBm**	**-7.8 dBm**
w/o FEC	-5.8 dBm	-5.6 dBm	-5.0 dBm

Rx received power (OMA)

These results are based on the use of silicon germanium photodetector embedded in the silicon photonics die.
The use of InGaAs photodetectors (which is a viable option for low-cost silicon photonics transceiver designs) is estimated to increase link budget by at least 1.5 dB, but to maintain very low silicon photonics transceiver relative costs germanium is preferred.

Summary of link budget test results



Description	Value	unit
Signaling rate lane(range)	25.78125	GBd
Center wavelength(range)	1240 to 1340	nm

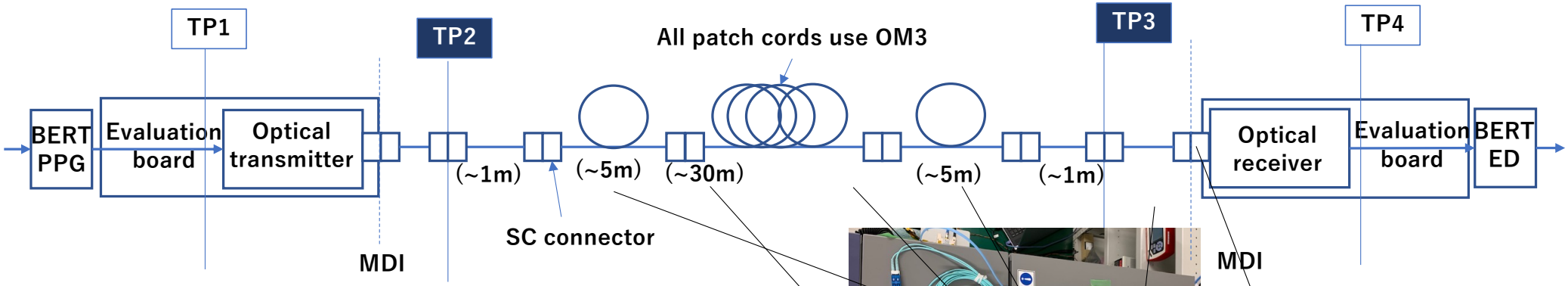
Description	Value	unit
Optical Modulation Amplitude(OMA)(max)	3	dBm
Optical Modulation Amplitude(OMA)(min)	-1	dBm
Extinction ratio(min)	4	dB
Encircled flux	TBD	

Margin
10 dB to 6 dB

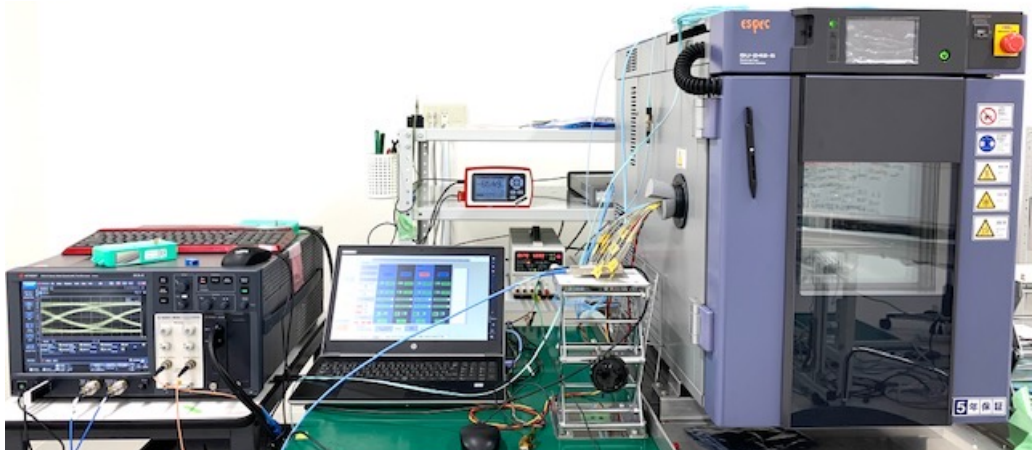
Description	Value	unit
Average receive power (min)	-7(1)	dBm
Receive power (OMA) (max)	3(1)	dBm

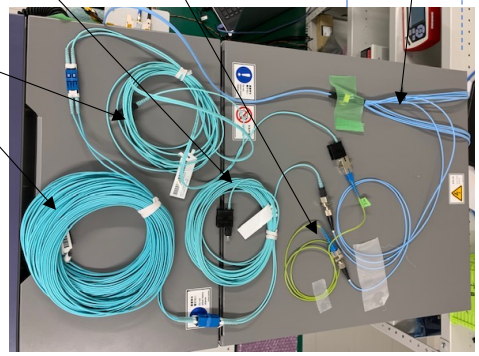
(1) Receiver power is defined at 5×10^{-5} based on IEEE802.3bm

25G_Si-Ph_MMF 40m test block diagram

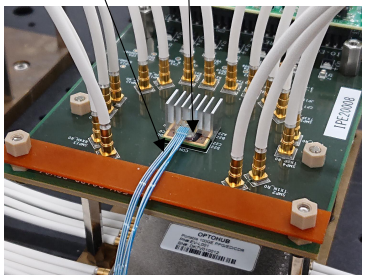


40 m x 4 connections, plus 2 extras





Optical Transceiver

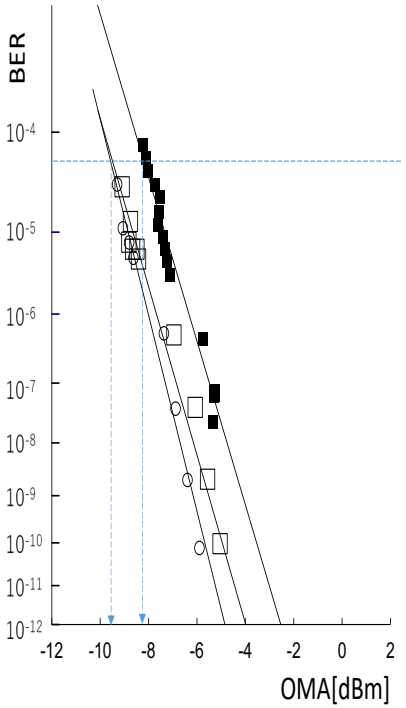


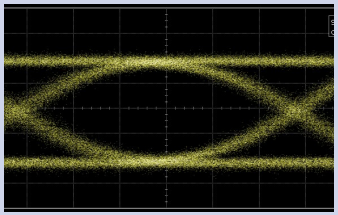
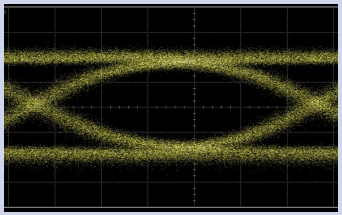
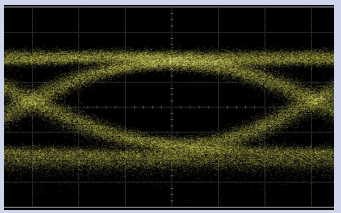
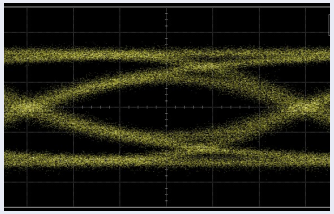
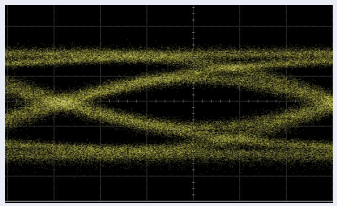
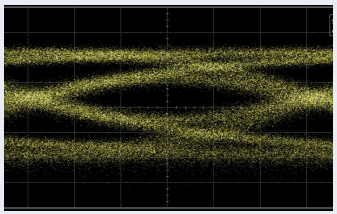
Receiving power (OMA) at TP3

Slight waveform degradation depending on the fibre bandwidth is observed.

Jitter except ISI hardly changes after 40 m transmission.

The receiver sensitivity is affected by the decrease in OMA of the optical input waveform due to band degradation, but the effect is small and estimated to be about 0.5 dB.



	Tj=60°C	Tj=105°C	Tj=125°C
Waveform@TP2			
Waveform@TP3			
Receiving power(min)	-9.6[dBm]	-9.5[dBm]	-8.2[dBm]

25G_Si-Ph_MMF transmission optical specifications

Description	Value	unit
Signaling rate lane (range)	25.78125	GBd
Center wavelength (range)	1240 to 1340	nm
RMS spectral width (max)	4	nm
Average launch power (max)	5	dBm
Average launch power (min)	0	dBm
Optical Modulation Amplitude, OMA (max)	3	dBm
Optical Modulation Amplitude, OMA (min)	-1	dBm
Launch power in OMA minus TDEC (min)	TBD	dBm
Transmitter and dispersion eye closure, TDEC (max)	TBD	dB
Average launch power of OFF transmitter (max)	-30	dBm
Extinction ratio (min)	4	dB
Optical return loss tolerance (max)	12	dB
Encircled flux	TBD (>86% at 19 um, <30% at 4.5 um)	
Transmitter eye mask definition (X1,X2,Y1,Y2,Y3)	{0.3,0.38,0.45,0.35,0.41,0.5}	

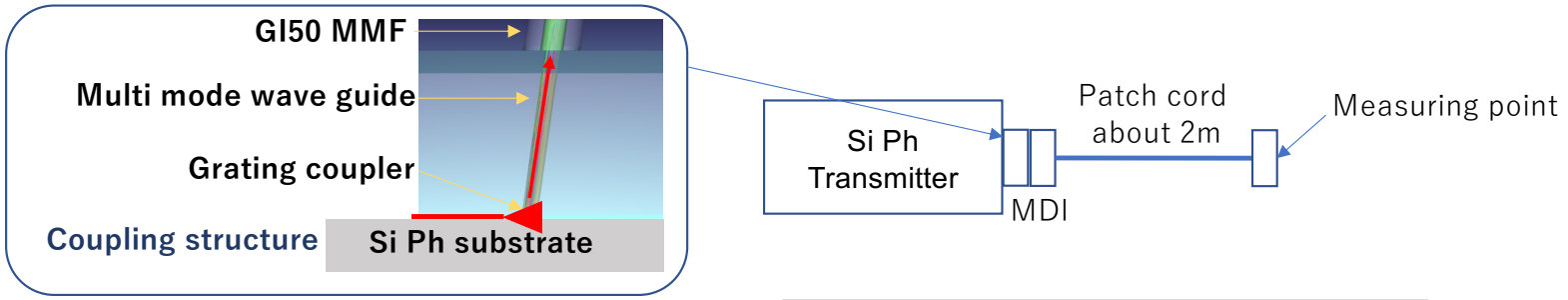
25G_Si-Ph_MMF receive optical specifications

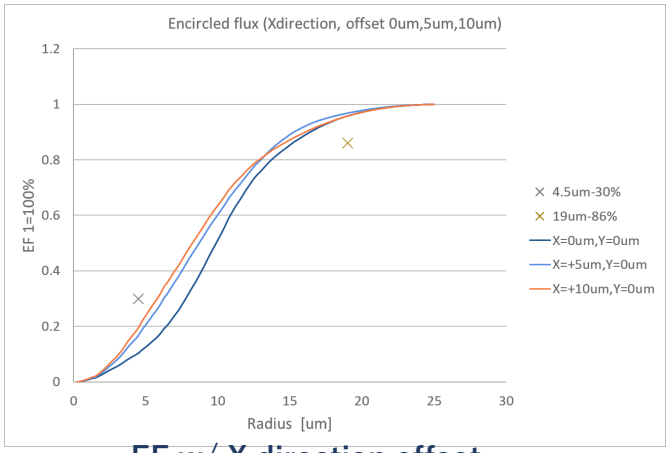
Description	Value	unit
Signaling rate lane (range)	25.78125	GBd
Center wavelength (range)	1240 to 1340	nm
Damage threshold (min)	4	dBm
Average receive power (min)	-7(1)	dBm
Receive power, OMA (max)	3(1)	dBm
Receiver reflectance (max)	20	dB
Stressed receiver sensitivity, OMA (max)	TBD	dBm
Conditions of receiver sensitivity test	TBD	

(1) Receiver power is defined at 5×10^{-5} based on IEEE802.3bm

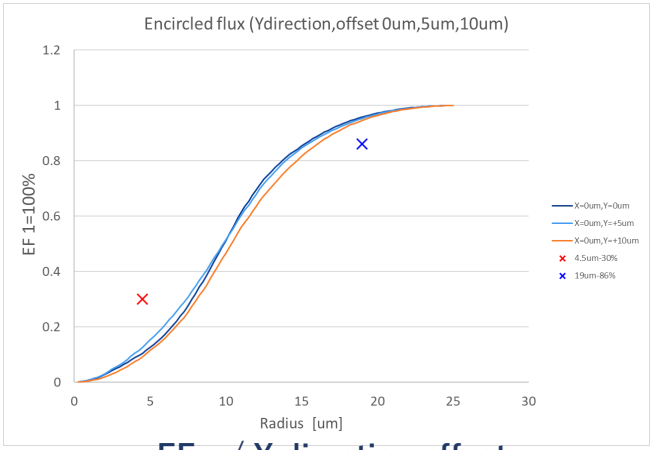
Considerations for launching condition

The 40 m transmission experiment indicates that the transmission distance is longer than the determining length with enough available bandwidth.
In the case of Si-Ph Tx using a grating coupler and a short multimode optical waveguide, it is considered that the launched modes are lower than the EF distribution.
The relationship between bandwidth and modal power distribution of the fibre should be discussed.





EF w/ X direction offset

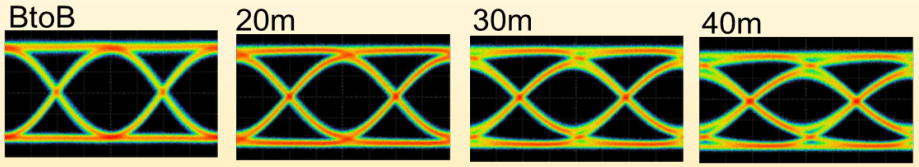


EF w/ Y direction offset

Consideration of applicable fibre

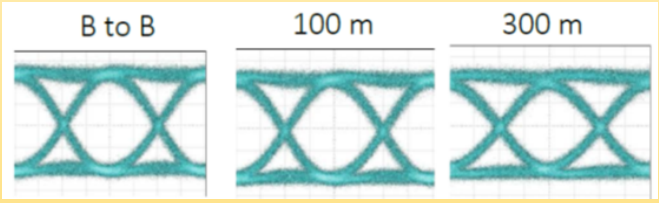
Tx waveform using Si-Ph optical transceiver

OM3 :40m @25Gbps by lower mode launch



The maximum transmission distance of 40 m depends on the launch condition of the Si-Ph transceiver.

Optimized fibre tuned to 1310 nm transmission
300m-500m @ 25Gbps *2



BW of 750MHz･km may be reasonable target for 40m at 25 Gbps

GI POF

Higher bandwidth will be expected, need information

Proposal of applicable fibre category

Parameter	OM3	OM3 *1	Customized fibre	GI POF	unit
Distance	15m	40m	40m	TBD	m
BW	500	750 *2	750	TBD	MHz・Km
Loss	<1	< 1	< 1	TBD	dB/km

*1：The relationship between the launch condition to the fibre and the bandwidth of the fibre should be discussed more.

*2 : Xin Chen et al., 2: 25 Gb/s transmission over 820 m of MMF using a multimode launch from an integrated silicon photonics transceiver
OPTICS EXPRESS, January 2014 | Vol. 22, No. 2

PMD considerations

25G PMD

For transmission specifications over 40 m the actual bandwidth of fibre including launch conditions should be discussed.
The loss of the optical connector for GI MMF are lower than those for SI-MMF (2 dB to 2.5 dB)
The attenuation of fibre length, 40 m with 4 inline connectors should be discussed further.

50G PMD

The Si-Ph can support frequency characteristics over 30 GHz, and it is considered that both NRZ and PAM4 are possible in 50G, but the following discussion is necessary:

- Whether NRZ or PAM4 is the best choice for 50G remains to be seen.
  - See Ramp session of OFC 2021: "*future optimal solutions should be discussed further, including modulation schemes*"

<10 Gbps

<10 Gbps optical transceivers already have a lot of commercial experience, and we think it would be a good idea to modify existing standards to meet high-temperature operation and reliability requirements.
In this case, it is necessary to decide what should be specified as the optical light condition for the automobile.

Summary

Link budget

- **link budget for 25 Gb/s PRBS^{31} at $T_{junction}$ = 125 ℃ and $T_{ambient}$ = 105 ℃ over OM3 fibre**
  - With FEC
    - 7.8 dB (average)
  - Without FEC
    - 5 dB (average)

These results are based on the use of silicon germanium photodetectors embedded in the silicon photonics die.
The use of InGaAs photodetectors (which is a viable option for low-cost silicon photonics transceiver designs) would increase the link budget by >1.5 dB.

Fibre choice

- OM3 would be suitable for 15m lengths
- 1310 nm optimised fibre would be suitable for 15m and 40m lengths
- Experimental evidence with silicon photonics transceiver under test indicates OM3 suitable for 40m, however John Abbot's strong contribution on 14th July shows that OM3 may not be suitable for 40 m lengths assuming EF launch
- Silicon photonics transceiver launch from grating coupler and short multimode "optical pin" will result in a modal power distribution, which is lower than EF and is assumed to meet bandwidth requirements for OM3 over 40m, however further discussion is required.
- POF bandwidth suitability at 1310 nm needs to be determined


THANK YOU