# On Board Optical Module

# LIGHTPASS®-EOB 100G

I-PEX has developed the LIGHTPASS®-EOB 100G on-board optical module. This document describes the detailed contents of that optical module. The following are its typical features.

- The on-board ultra-thin optical transceiver is designed for near-packaged optics (NPO) and enables 100 Gbps transmission.
- The light source is mounted on an optical transceiver engine, and no external light source is required.
- The laser is a quantum dot laser, ensuring sufficient lifetime and reliability even in high temperature operation.
- To create a low-profile module, a diagonal-cut fiber array is used, which results in a module height of 2.3 mm.
- It has a high heat dissipation structure, and maintains error-free (BER < 1E-12) performance, even at a case temperature ($T_c$) of 105°C.
- It can be used in a wide range of applications(e.g., test equipment, sensors, cameras, robots, medical, aerospace, and vehicles.

The key features of the LIGHTPASS product family are:

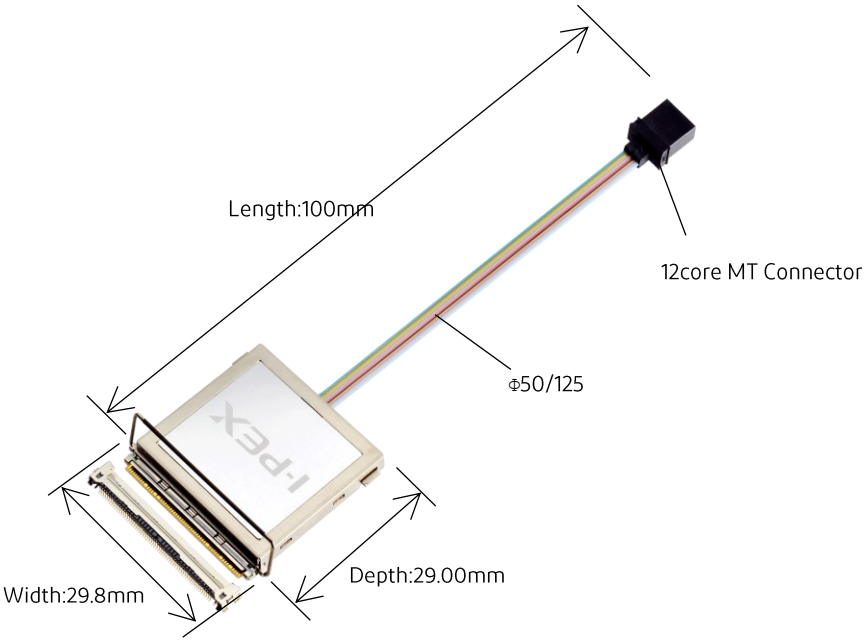
# 1: Ultra-thin optical module

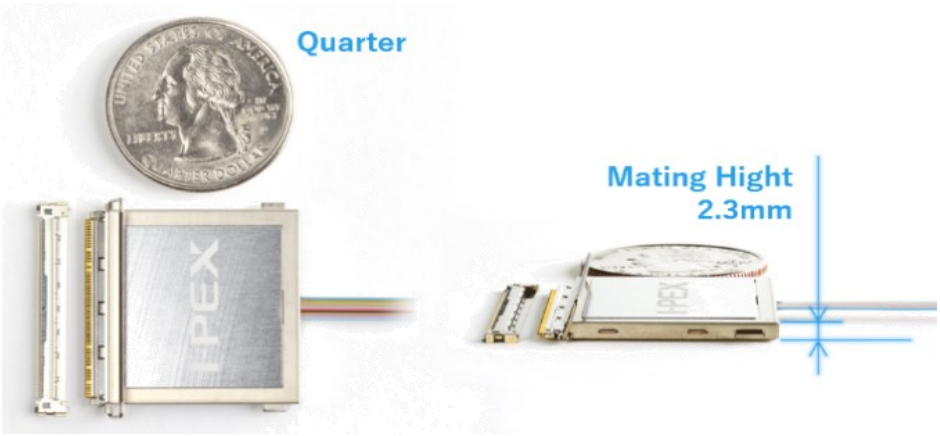
1) LIGHTPASS®-EOB 100G

The ultra-thin optical module EOB (Embedded Optical Blade) takes its name from the general term EOM (Embedded/Electro Optical Module), which describes an optical-electrical conversion module.

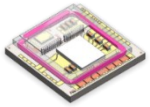
Product Specifications

- Transmission rate: 100 Gbps (NRZ, 25 Gbps x 4 channels) bidirectional
- Size: (W) 29.8 mm x (D) 29.0 mm x (H) 2.3 mm
- Optical fiber: Φ50/125 MMF
- Wavelength: 1310 nm
- Electronics Interface: CABLINE®-CA 0.4 mm pitch, 60 pin, Horizontal mating connector with mechanical lock
- Optical interface: 12-core MT connector, 250 μm pitch
- Operability: Built-in MCU, no user control required
- Operating temperature range: -40°C ~ +85°C (+105°C) case temperature
- Safety: Class 1





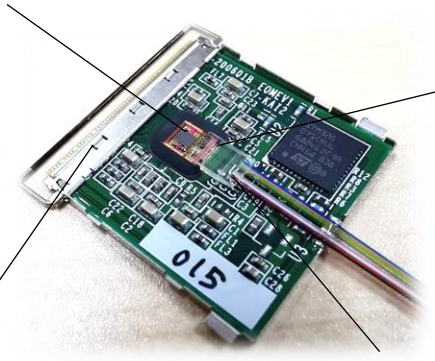

2) Components

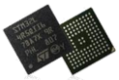


IOCore®

・Optical transceiver with built-in TX and RX using silicon photonics technology.

・100Gbps NRZ (25Gbpsx4ch Tx/Rx) NRZ.1310nm MMF





MCU

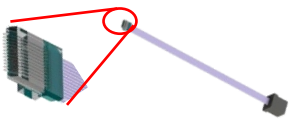
・Monitors IOCore® temperatures and supply voltages

No detailed adjustments are required on the part of the user. Operates with power supply only.

Fiber Array

・50/125 Multimode Optics

・Withdrawal by MT ferrule



CABLINE®-CA/CAF

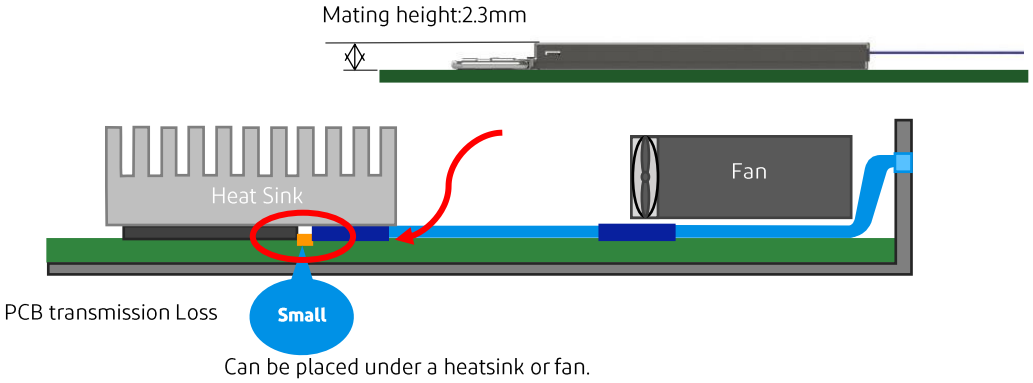
・High Speed and Low-profile

・With locking structure

3) Feature

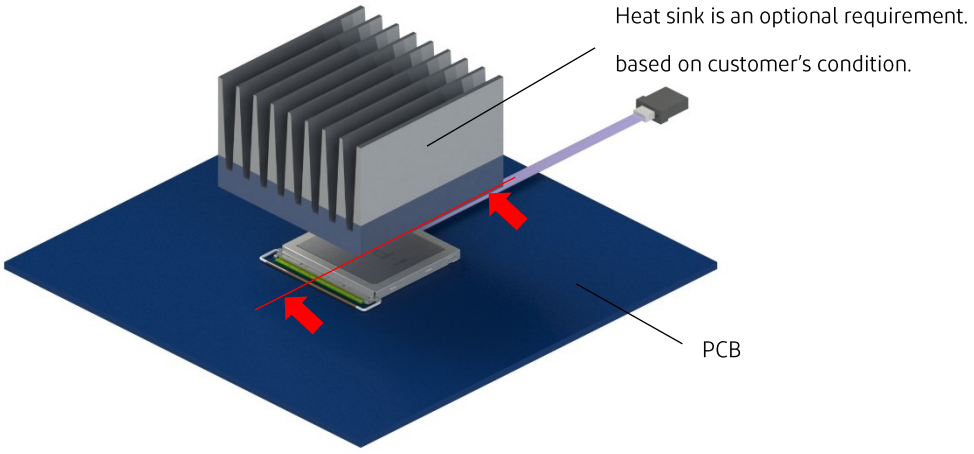
1. Ultra-thin construction

Low component height allows mounting under heat sinks and fans or placement near the ASIC, minimizing board transmission loss.

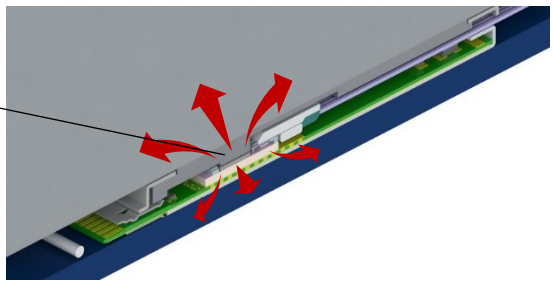



2. High heat release mechanism

Heat is diffused by thin, metal shell and flat structure.

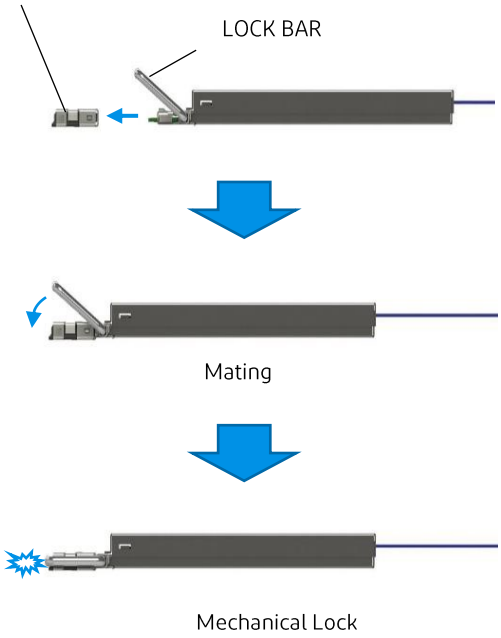


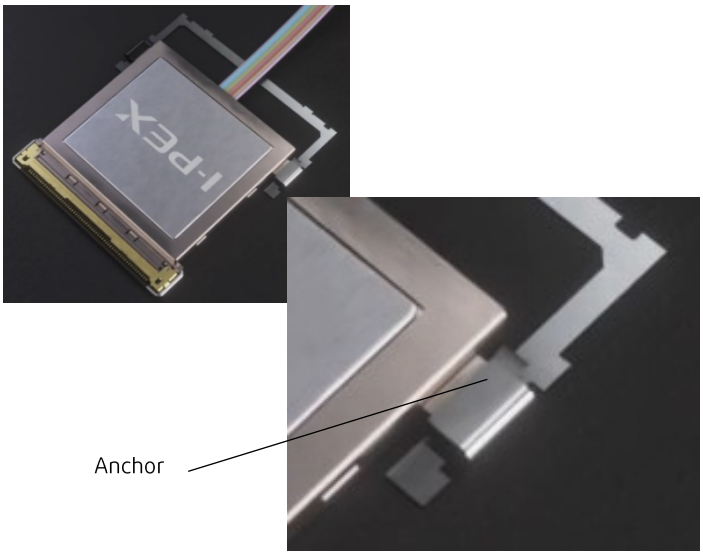

To the upper heat sink and the lower board
Efficiently diffuse heat from the module



3. Mechanical locking structure

Locking bars on connectors prevent half-mating and un-mating, and anchors prevent optical modules from floating due to vibration.



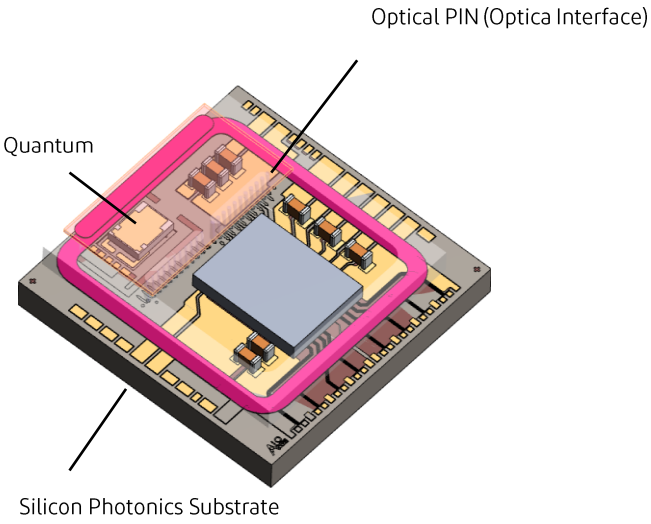



# 2: Ultra-small optical transceiver engine

The optical IOCore® is a 5 mm square optical transceiver chip manufactured using silicon photonics technology developed by AIO CORE Co., Ltd. The optical element is on a silicon substrate and has a transmission speed of 25 Gbps per channel, enabling bidirectional communication with a total transmission speed of 100 Gbps on 4 channels of TX and RX.

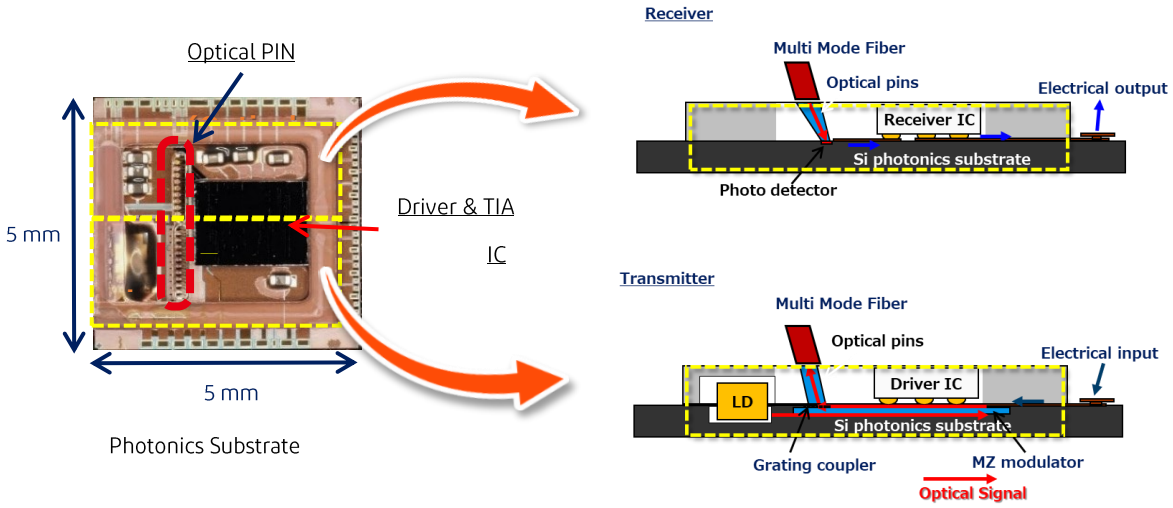
1) Design Feature

- Ultra-small, high-density package
  (All TX and RX functions are integrated on a 5 $mm^2$ silicon chip)
- Wide operating temperature range
  (Quantum dot laser is capable of operating from -40~85°C)⇒ With plans to be expanded to 105°C
- High reliability
  (Uses high-efficiency and high-reliability quantum dot lasers)
- Easy fiber coupling technology
  (Optical pin structure with sufficient tolerance allows passive optical coupling)
- Low cost
  (All manufacturing processes are automated to achieve high productivity and lower cost.)



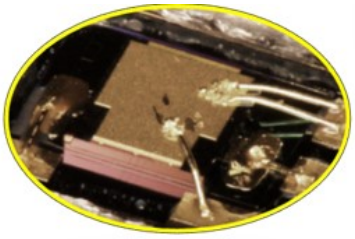
2) Structure of Optical IOCore®

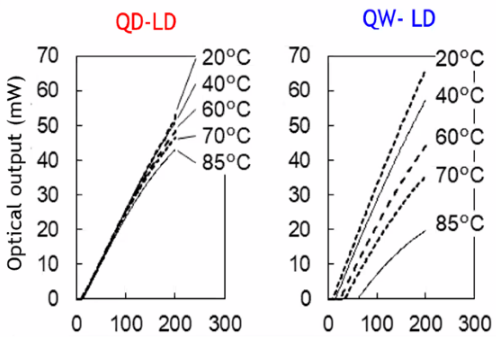
A receiver with a photodiode (PD)and transimpedance amplifier (TIA), and a transmitter with a laser diode (LD), modulator, and grating coupler, are both built into a 5 $mm^2$ silicon chip.
On the receiving side, optical signals from the optical fiber at the top are received by the PD mounted on the silicon substrate through optical pins, and electrical signals are transmitted to the module substrate through the electrode on the chip end via the TIA.
On the transmitting side, the light from the LD is modulated and converted to an optical signal based on the electrical signal drawn from the electrode at the end of the chip. Through the optical waveguide, the signal is bounced up to the optical pin by the grating coupler and drawn into the optical fiber equipped on the top.




3) Quantum Dot Laser Diode (QD-LD)

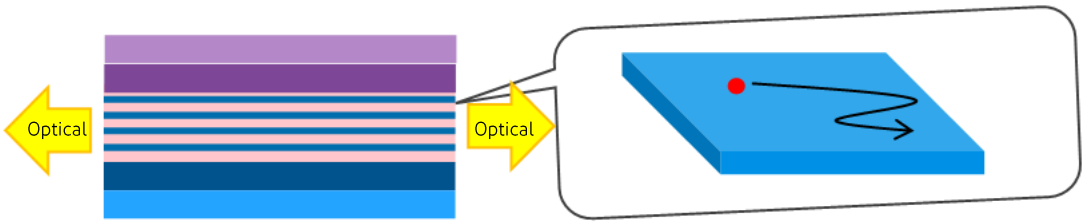
We use a quantum dot laser (QD-LD) as a light source, capable of maintaining high output even at high temperatures. QD-LD exhibits high reflection resistance and favorable Relative Intensity Noise (RIN) characteristics, minimizing issues related to noise and signal quality in communication systems. Additionally, it is more stable and has less performance variation with temperature compared to conventional LDs.





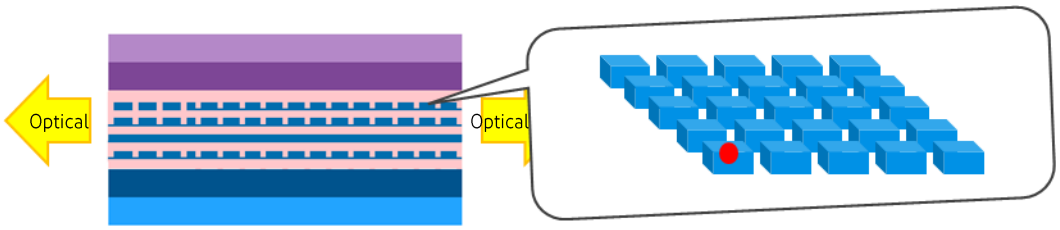

I-L characteristics

Conventional Laser Diode (Quantum Well)




The active layer of conventional LDS where electrons are confined one-dimensionally. The problem arises from the degradation of characteristics at high temperatures due to increased electron mobility with temperature variation.

QD-LD (Quantum Dot)

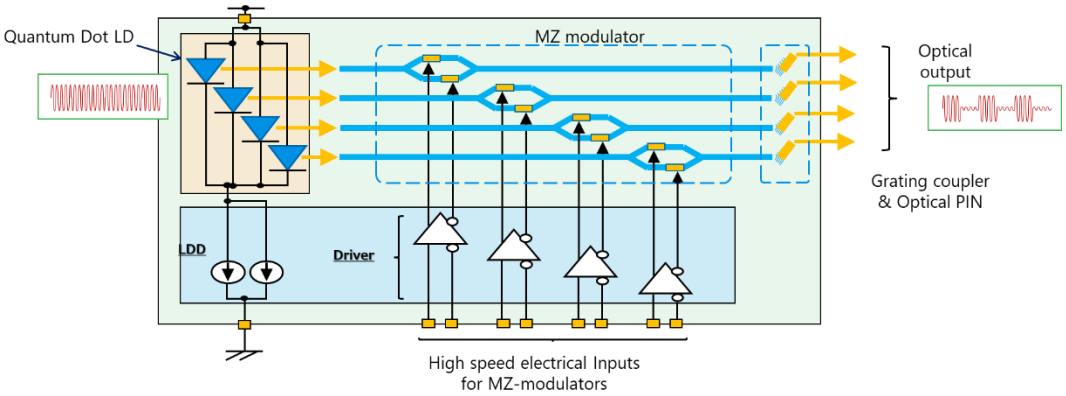



A laser utilizing quantum dots in the active layer.

The energy of electrons confined in quantum dots is limited, resulting in minimal changes in electron states even with temperature increases, leading to a significant improvement in temperature characteristics. Quantum dots are tiny semiconductor particles with sizes on the order of 10nm, approximately the wavelength size of electrons.

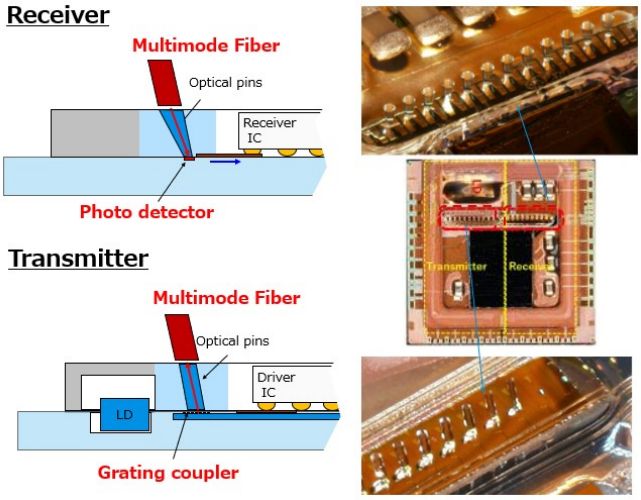
4) Transmission of Optical IOCore® (electrical to optical)

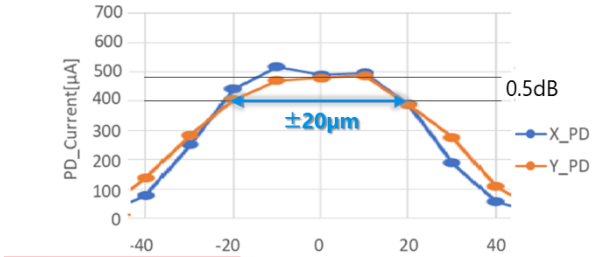
The IOCore® utilizes Mach-Zehnder (MZ) modulators with low temperature sensitivity. The modulation efficiency of the MZ modulator is given by the equation C×V (C = capacitance, V = supply voltage). Since C is independent of temperature and the modulation voltage remains constant, the frequency bandwidth remains stable over a wide temperature range. As a result, we can achieve very stable optical output waveforms with minimal jitter over a wide temperature range.



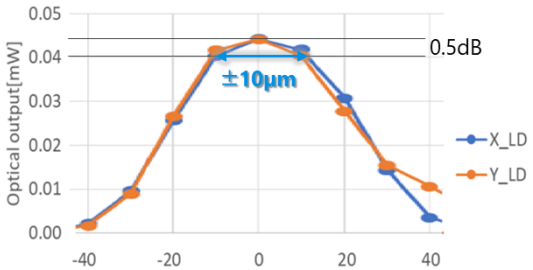

5) Optical Coupling Structure

LIGHTPASS® products use optical pins at the coupling section between the optical components mounted on the silicon substrate of the optical transceiver chip and the optical fibers. Similar to the core section of the optical fiber, at the boundary surface of the optical pin, light is reflected and contained within, preventing leakage. Thus, on the receiving end, the optical pin serves a funnel-like role in connecting the light signal from the optical fiber to the photodetector, while on the transmitting end, it serves to convey the light signal reflected from the grating coupler to the optical fiber. We ensure coupling tolerances of ± 10μm or more on both the receiving and transmitting ends.




Rx interface tolerance




Tx interface tolerance

6) Temperature Sensitivity of Optical Coupling

The optical coupling section on the transmitting side, namely the light emission section from the optical pin, exhibits temperature sensitivity. This is due to the temperature-dependent wavelength of the LD, which shifts by 0.6 nm per 1°C change in temperature. Furthermore, the emission angle of light from the grating coupler is wavelength-dependent, shifting by 0.083° per 1 nm change in wavelength.

As a result, the emission angle from the grating coupler changes by 0.05° per 1°C change in

temperature, leading to a variation of ± 3.6° in angle over a temperature range of -40°C to 105°C. Considering the numerical aperture of the optical pin, which is 0.4 or higher, and the maximum incident angle of 23.6°, a sufficient incident angle is ensured. Therefore, even if the angle changes due to temperature variations, the light entering the optical pin can convey the light signal to the upper fiber without leaking externally.

QD-LD : Wavelength shift 0.6 nm/°C

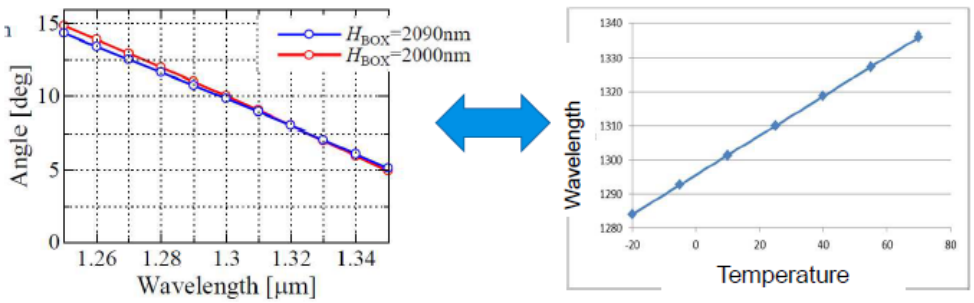
Grating coupler: exit angle shift 0.083 degrees/nm

Radiation angle changes: 0.05degree/°C

in the range of - 40 ~ 105 °C

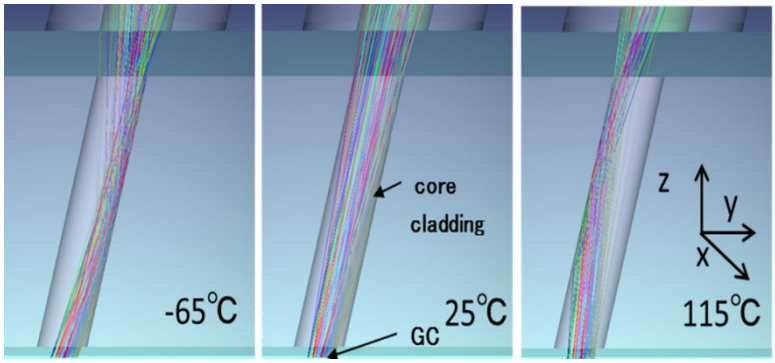
Angle change of output light occurs

by about ± 3.6°



7) Optical Axis Analysis of Optical Coupling

Based on the optical axis analysis, it has been confirmed that the light emitted from the grating coupler undergoes changes without leaking from the optical pin and is effectively transmitted to the upper fiber.



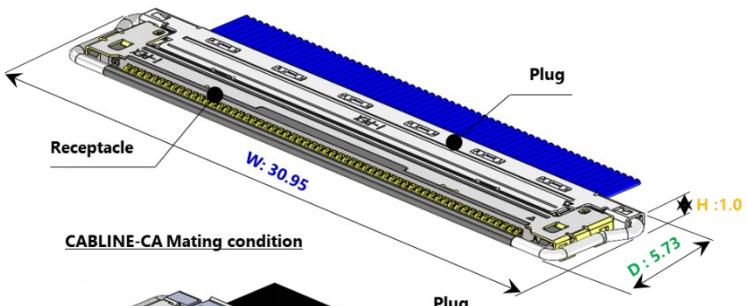

The variation in emitted light angle with temperature. 0.05deg/℃

# 3: High-speed, low-profile electrical connectors

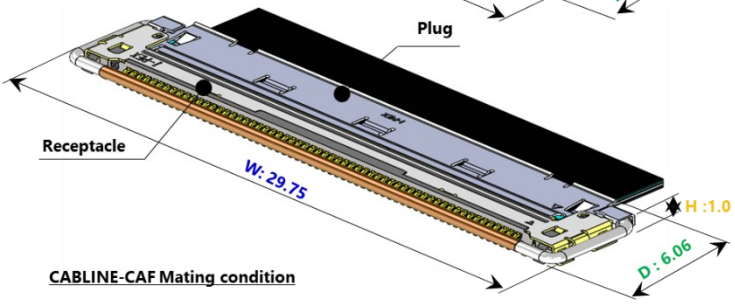
To develop a high-speed and low-profile optical module, we use a CABLINE® connector.
Features of CABLINE®-CA/CAF and CABLINE®-CA is a 0.4 mm pitch connector. Even with a 60-pin connector, the occupied area on the board is only 30.95 mm in width and 5.73 mm in depth, making it an ultra-compact, low-profile connector with a height of 1.0 mm.

Its features include a mechanical lock bar, which prevents incomplete mating or accidental disengagement. CABLINE®-CA is a connector designed for handling multiple micro-coaxial cables (mainly for transmitting differential signals or control signals). It has multiple ground connections and excellent high-frequency transmission characteristics. Additionally, CABLINE®-CAF is designed to accommodate FPCs into the plug shell and is compatible with the same CABLINE®-CA receptacle.
CABLINE®-CA/CAF Outline

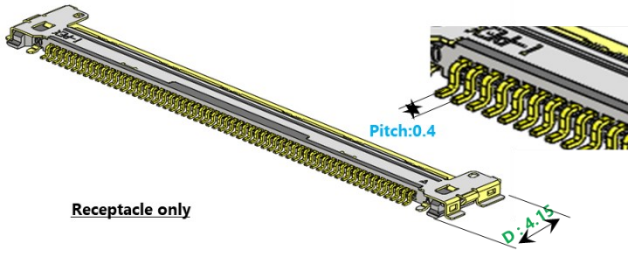
| | | |
|---|---|---|
| ■ Name | CABLINE-CA / CAF | |
| ■ Mating Type | Horizontal mating type | |
| ■ Pitch | 0.4 mm | |
| ■ Pin count | 60 pin | |
| ■ height : | Mating condition | : 1.00 mm |
| ■ Depth : | Mating condition | : CA 5.73 mm<br>CAF 6.06mm |
| | Rece only | : 4.15 mm |
| ■ Width : | CA : 30.95 mm<br>CAF : 29.75 mm | |
| ■ 製品規格／TR: | CA : PRS-1968／TR-16023<br>CAF : PRS-2465／TR-18016 | |




CABLINE-CA Mating condition




CABLINE-CAF Mating condition



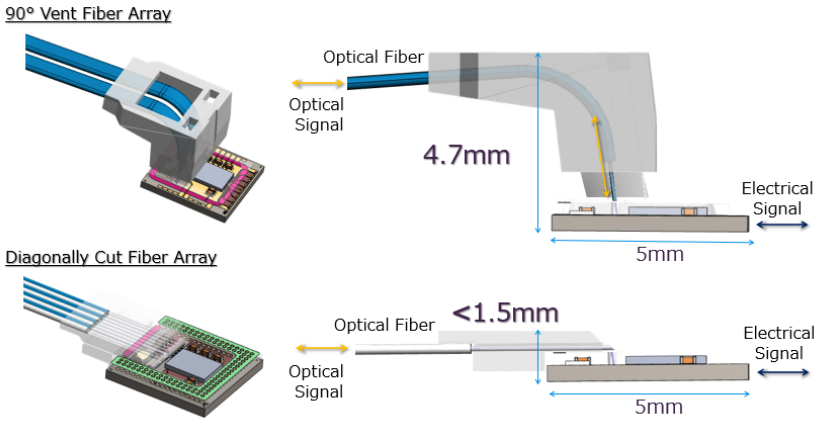

Receptacle only

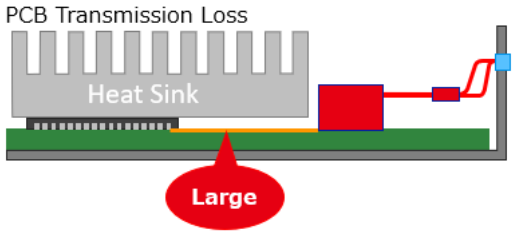
# 4: Ultra-low-profile fiber array

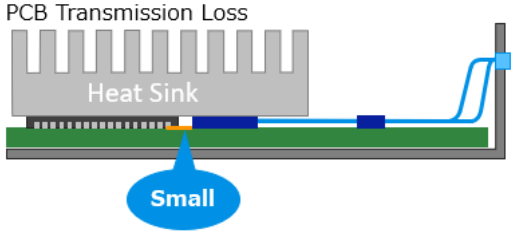
In the development of the LIGHTPASS® -EOB 100G ultra-thin optical module, it was necessary to adopt diagonally cut fibers instead of fibers bent at 90 degrees, to achieve a low-profile design. Here's an explanation of the purpose behind this decision and the details of the fiber array.

1) Reduced Height through Diagonally Cut Fiber Array

The implementation of a diagonally cut fiber array has enabled a low-profile design, allowing optical modules to be positioned closer to ASIC. This placement has led to a reduction in transmission losses in substrate wiring. Additionally, it allows for a common heat dissipation design with ASICs.

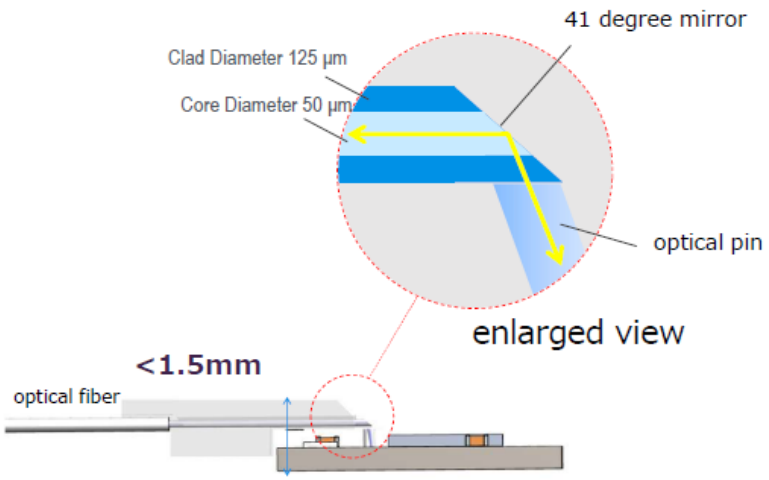


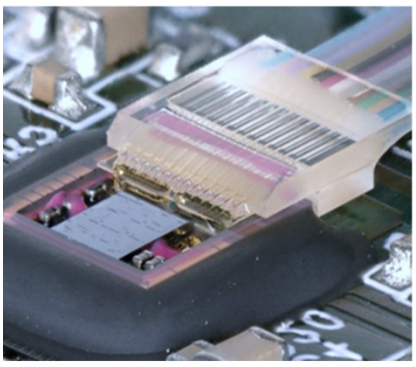



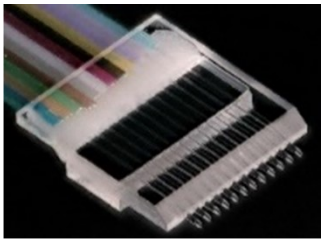



2) Diagonally Cut Fiber Array

Ultra-thin Fiber Array Utilizing Reflection from Fiber End-face Mirrors.
We applied a fiber array where fibers aligned on V-groove glass were diagonally cut to serve as mirrors. This approach effectively reduced the height of the fiber block, achieving a module height of 2.3 mm.

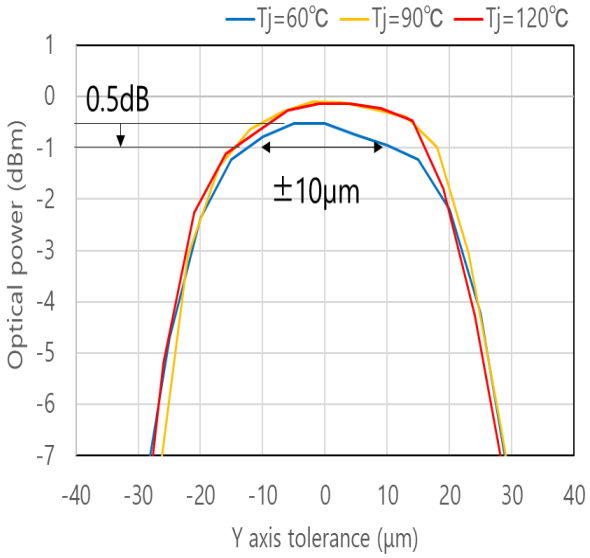


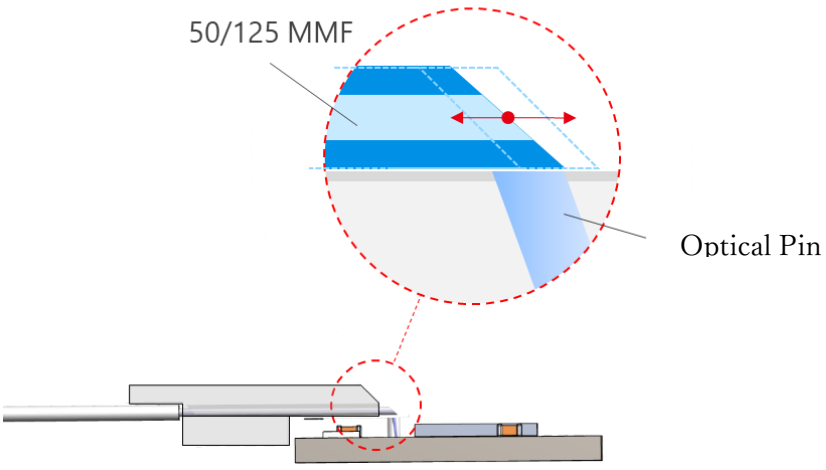





3) Alignment Tolerance of Diagonally Cut Fiber Arrays

Fibers achieve alignment tolerances of ± 10 μm or greater over a wide temperature range.



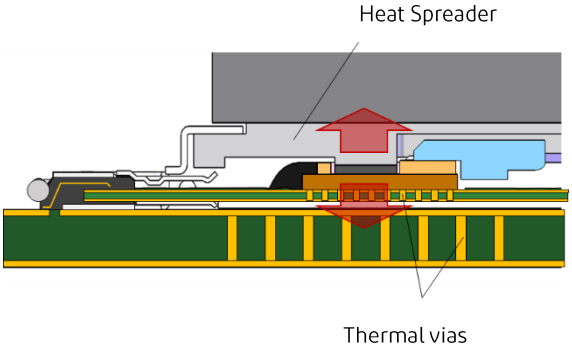



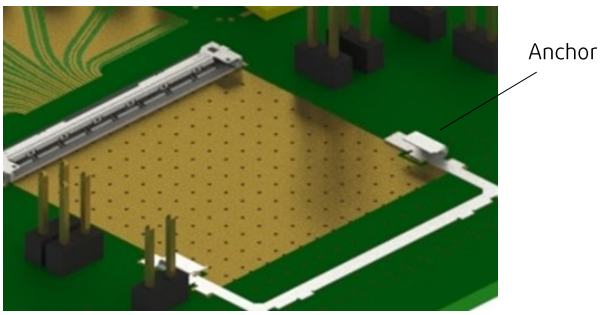
# 5: High heat dissipation module structure

The superior heat dissipation of LIGHTPASS® is achieved through a specific structural design that enables it to maintain a $\Delta T_{j\text{-}c}$ of ≤ 15°C. This explanation will focus on how LIGHTPASS's construction contributes to such effective thermal management.

1) The heat dissipation structure

Efficient heat dissipation in the vertical direction is achieved through horizontal mating and a flat module design. To efficiently transfer heat to the heat sink located on the top, a heat spreader is integrated into the module structure. Utilizing anchor components to press the module onto the mounting substrate enhances heat dissipation efficiency towards the bottom of the module.

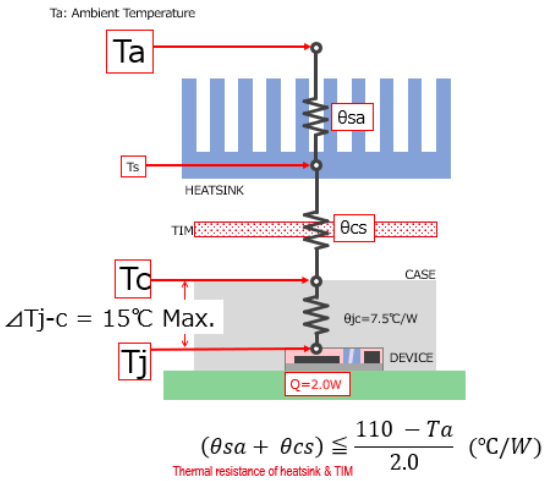


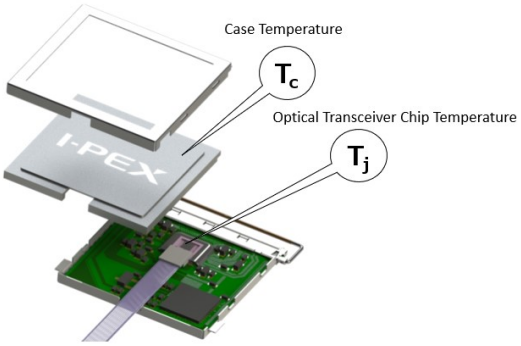




2) Heat dissipation specifications.

$\Delta T_{j\text{-}c} \leqq 15℃$

Efficient heat dissipation is optimized not only in the upward direction but also towards the downward direction, ensuring a temperature difference ($\Delta T_{j\text{-}c}$) ≤ 15℃ between the operating optical transceiver chip temperature ($T_j$) and the case temperature ($T_c$).




# 6: Optical transceiver module evaluation results

The optical module was placed in an environmental test chamber ($T_a$ = 105°C), and 25.781 Gbps NRZ signals were applied to each lane from a BERT. In a loopback configuration where the optical signals were sent from the transmitter to the receiver side of the module, the operational state was evaluated for both heat dissipation and transmission performance.

Fig 1. Test condition.

1) Heat Dissipation

under high-temperature conditions (Ta=105°C), the heat dissipation performance allows the operation to remain below the chip's maximum operating temperature (Tj=120°C), ensuring it can be driven within specifications (△Tj-c < 15°C)

| Temp. [°C] | Sample 1 | Sample 2 |
|---|---|---|
| Ta(Ambient Temp.) | 105.0 | |
| Tc(Case Temp.) | 106.4 | 106.3 |
| Tj(Junction Temp.) | 117.9 | 118.3 |
| Δ Tj-c(<15°C) | 11.5 | 12.0 |

Table 1. Case Temperature and Chip (Junction) Temperature in Module Operating Conditions

2) Tx Optical Output Waveform

Good eye opening was confirmed even in a high temperature environment (Ta = 105 °C).

| Ta Ambient Temp. | 105°C |
|---|---|
| Clock Rate | 25.781 Gbps |
| PRBS | 31 |
| LDD Current | 100mA/ch |
| Pre/Post Emphasis | on |

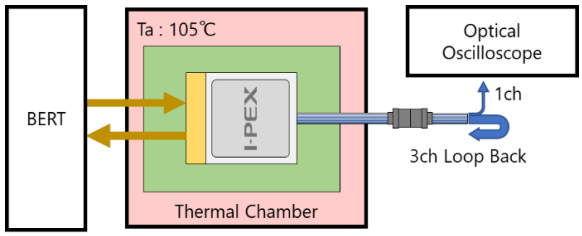



Figure 2-1. Measurement Conditions and Measurement System for Tx Output Waveform

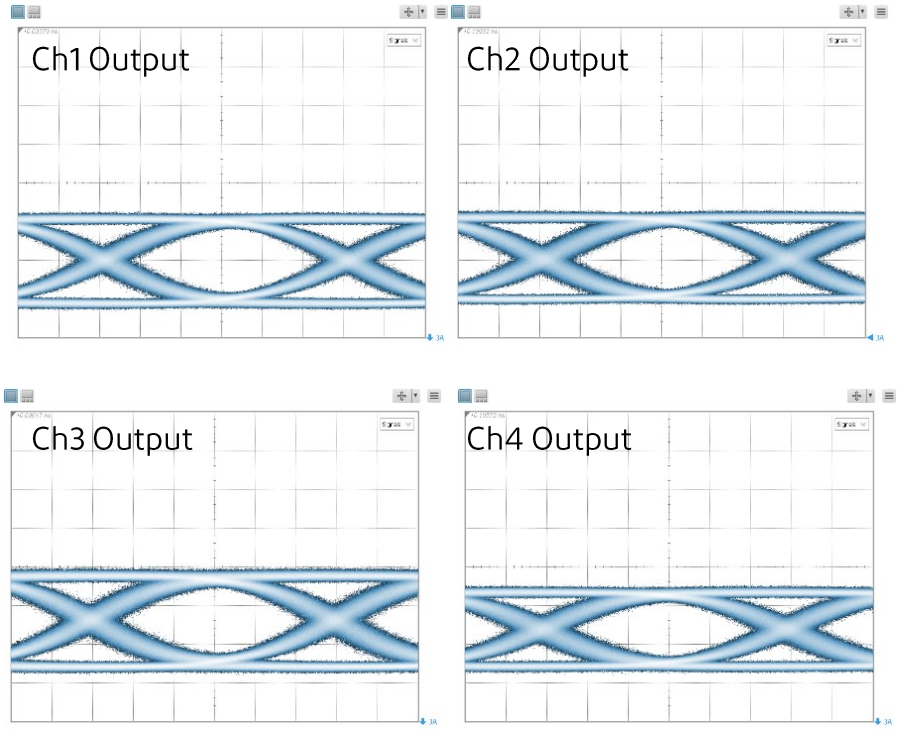



Figure 2-2. Tx Output Waveform

3) Rx Input Sensitivity

The optical signal from the reference optical module is attenuated through an attenuator until the BER (Bit Error Rate) is <10^-12, and the OMA (Optical Modulation Amplitude) = Input Sensitivity is measured. Even under high-temperature conditions (Ta=105°C), an input sensitivity with an OMA penalty of approximately 1dB is confirmed.

| | |
|---|---|
| Ta Ambient Temp. | 105°C |
| Clock Rate | 25.781 Gbps |
| PRBS | 31 |
| LDD Current | 100mA/ch |
| Pre/Post Emphasis | on |

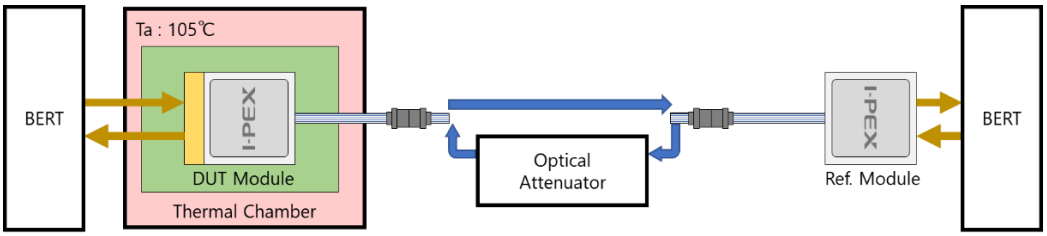



Figure 3-1. Measurement Conditions and Measurement System for Rx Input Sensitivity

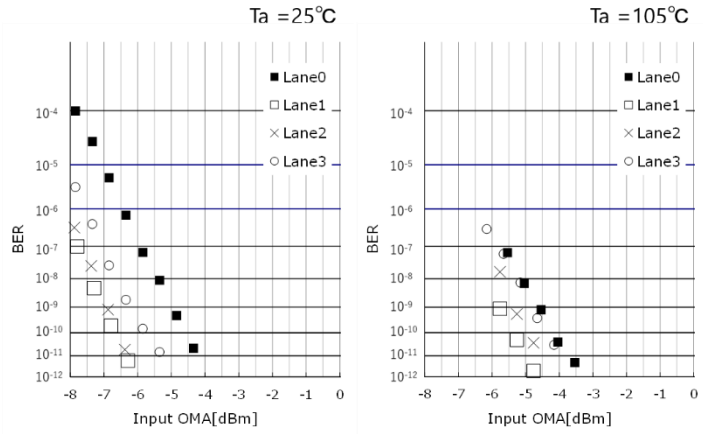



Figure 3-2. Results of Rx Input Sensitivity Measurement

4) Result of Loopback BER

In the loopback configuration, BER < 1E-12 was verified for 25 Gbps per lane NRZ PRBS31 transmission across all temperature ranges.

| | |
|---|---|
| Ta Ambient Temp. | 105°C |
| Clock Rate | 25.781 Gbps |
| PRBS | 31 |
| LDD Current | 100mA/ch |
| Pre/Post Emphasis | on |

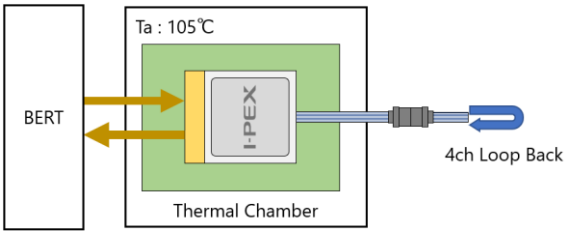



Figure 4-1. Measurement Conditions and Measurement System for BER Error Free=1E-12

| Ta Ambient Temp. | -40°C | 0°C | 25°C | 85°C | 105°C |
|---|---|---|---|---|---|
| Lane 0 | Error Free | Error Free | Error Free | Error Free | Error Free |
| Lane 1 | Error Free | Error Free | Error Free | Error Free | Error Free |
| Lane 2 | Error Free | Error Free | Error Free | Error Free | Error Free |
| Lane 3 | Error Free | Error Free | Error Free | Error Free | Error Free |

Figure 3-2. BER Measurement Results

# Conclusion

The LIGHTPASS®-EOB 100G, equipped with the ultra-compact optical transceiver chip developed as an ultra-thin optical transceiver module, demonstrates stable operation across a wide temperature range. Its excellent heat dissipation and transmission characteristics are proven. Error-free operation (BER < 1E-12) was confirmed even at a case temperature of 105°C. Leveraging these outstanding features, it can be effectively utilized in a wide range of markets and applications.

The proposed industries and devices
Medical: Endoscopes, Medical Robots
Telecommunication: Base Stations (Antenna Units, Inter-device Connections)
Data Information: Network Interface Cards (NIC)
Broadcasting: Professional Broadcasting Cameras
Aerospace: Satellite (Internal network), Avionics

We are applying this technology to drive the development of Four additional LIGHTPASS® products.

LIGHTPASS®-EOB II 100G
LIGHTPASS®-EOB II 128G
LIGHTPASS®-EOS 100G
LIGHTPASS®-SP Q28