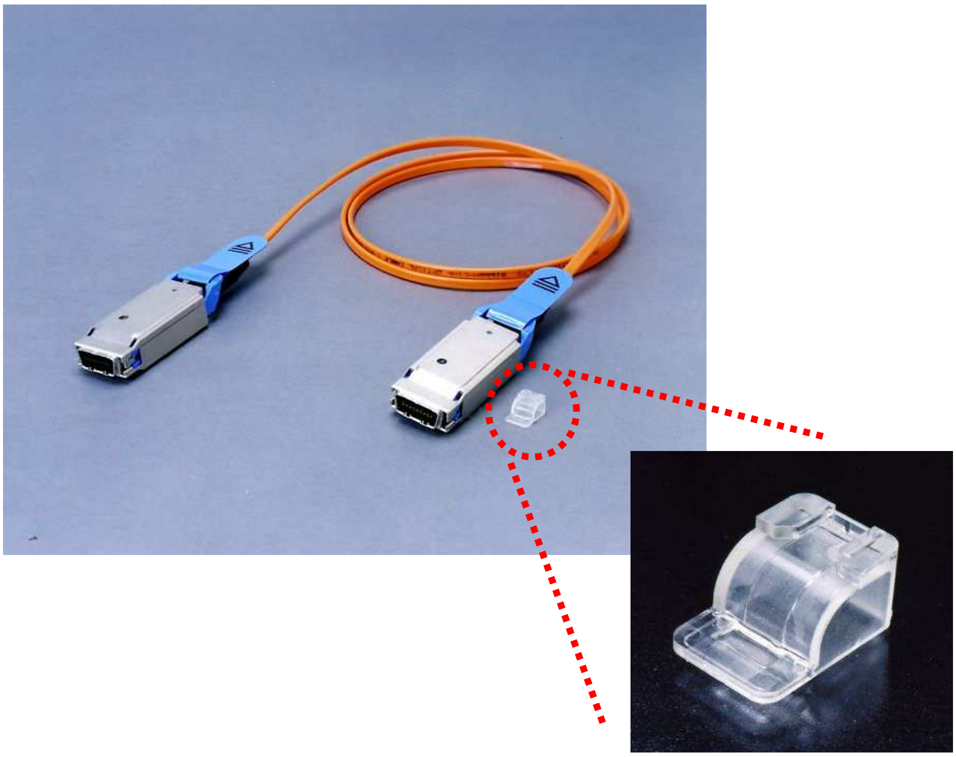
4-Channel Optical Parallel Transceiver

Using 3-D Polymer Waveguide



1 Description

Fujitsu Component Limited, in cooperation with Fujitsu Laboratories Ltd., has developed a new bi-directional 4-channel optical parallel optical transceiver, applying a three dimensional polymer waveguide newly developed as a pivotal optical platform to which optical devices and fibers are optically integrated or assembled. The waveguide provided a novel low-cost solution to simplify the complicated structure and process of optical assembly, and enabled optoelectronic devices and ICs to be mounted on a small single circuit board, which contributed to optimizing the high speed circuit design and assuring high signal integrity.

The optical parallel transceiver incorporates a 4-element 850nm VCSEL(Vertical Cavity Surface Emitting Laser) array lit by a Driver IC, a 4-element PIN photodiode array coupled with a Receiver IC, and a control IC for Driver and Receiver ICs. It has 8 independent channels(4 transmitters and 4 receivers) with an optical interface of 12-flber MPO connector and an electrical interface of the industry standard MDI connector for high speed copper interface specified in 10GBASE-CX4, InfiniBand 4X and 10G Fibre Channel standards. This transceiver is housed in a package equivalent to that of the industry standard CX4 MDI connector, and is hot-pluggable to the MDI port.

The transceiver is capable of transmitting data at 3.125Gbps(10GBASE-CX4) over typically 300m multimode fiber with 850nm wavelength. As the transceiver is bit rate-transparent and application-agnostic, it can also be applied to SDR (2.5Gbps) InfiniBand 4X or Fibre Channel (3.1875Gbps) systems, in addition to 10GBASE-CX4.

2 Features of the transceiver

- **Converts 4X microGiGaCN™ to 4X optical interface**
- **Optical 12-channel MPO connector interface**
- **Link reach: up to 300m at 3.125Gbps with standard multimode fibers(50/125 μm, 500MHz・km), and longer reach at 2.5Gbps.**
- **Single power supply of +3.3V, low power consumption of 0.9W(typ)**
- **Reliable 850nm VCSEL**
- **Operating case-temperature range: 0 to +70℃**
- **Waveguide-based stable integrated optics**
- **Hot pluggable electrical interface**
- **IEC Class 1M laser eye safety compliant**

3 Technical Details

3.1 Concept and structure of the waveguide

VCSELs/PIN photodiodes are planar devices that emit or receive the lightbeams perpendicular to its top surface. Therefore, the lightbeams must be converted in direction by 90 degrees and guided to fiber arrays perpendicular to the transceiver end-face (Fig. 1). This makes it difficult to simplify the structural design and assembly process of transceiver modules. In conventional design, discrete optical elements spatially aligned to each other have been used to form an optical subassembly, which is then mounted on the transceiver circuit board in an appropriate, usually normal direction to each other to guide the lightbeams to the fiber cables.

Optical design in parallel transceivers using planer optoelectronic devices requires such functions as;

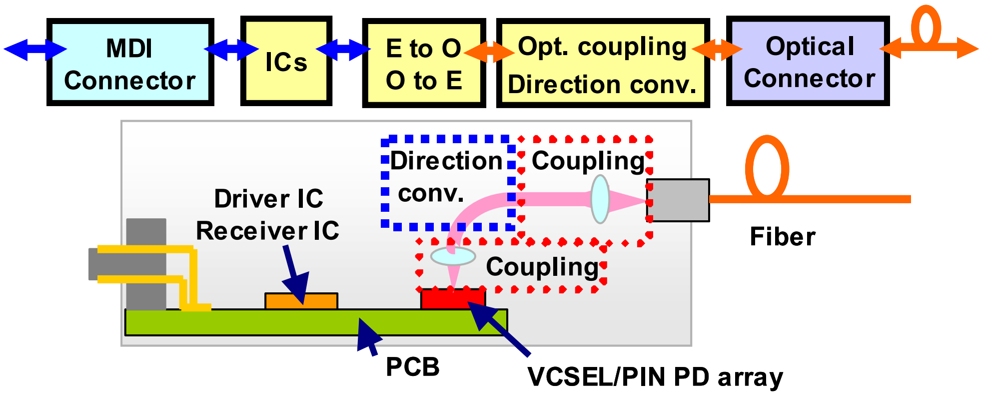


Fig. 1 Basic structure of parallel transciver

- Coupling and guiding the light of VCSELs to fibers attached at right angle to the VCSEL surfaces
- Coupling and guiding the light from fibers to PIN PDs at right angle to each other
- Efficient Coupling, low loss propagation, low loss bending equal to or less than that achieved by conventional micro-optics using microlens and/or prisms
- Optical coupling that allows wide alignment tolerance of optical parts
- Optical beam collimation to reduce cross talks between adjacent channels
- Pitch conversion capability, when need arises, to increase flexibility in parallel optics, which is preferable for future evolution to larger number channel optics
- Mechanical rigidity enough to support the MT ferrule

To achieve these multiple functions at low cost, waveguide optics is expected to be a promising candidate which can provide integrated solutions with large-volume productivity. We took this approach applying high precision injection molding to fabricate the base structure of the waveguide comprising base structure, integrated microlenses, and 8-rectangular grooves (50µm*50µm) into which core material are infilled. The basic structure of the waveguide is shown in Fig. 2.

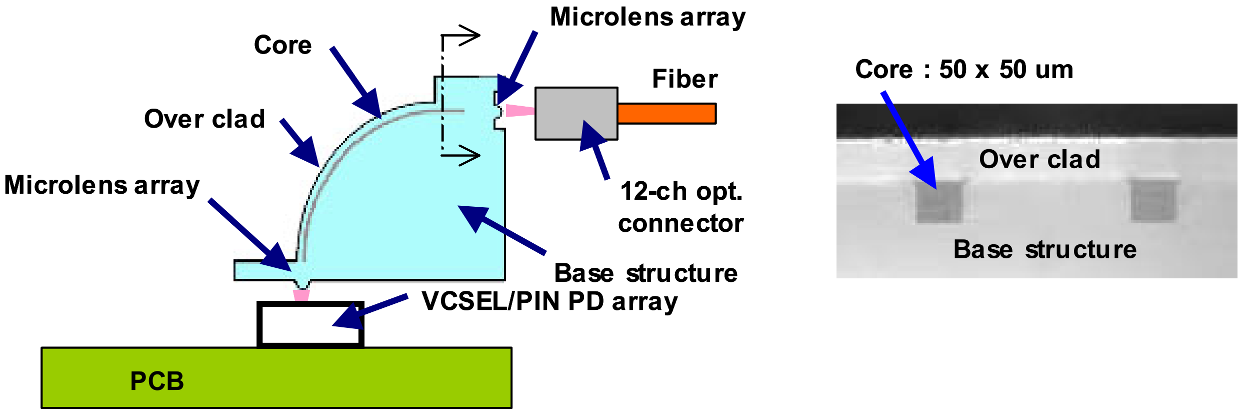
3.2 Design and fabrication of the waveguide

Requisites above are considered and incorporated into the design. The geometry and outer dimensions of the waveguide were determined by the layouts of the VCSEL/PIN PD chip arrays and VCSEL driver IC and Receiver IC bare chips that are mounted beneath the waveguide on the common circuit board. The radius of curvature and the length of the optical waveguide are 4mm and 10.5mm respectively, determined allowing for the conditions of bending loss and transceiver dimensions.

The base structure uses an olefin polymer well-proven as a precision injection mold material for optical use. A film made of the same material was used for over-cladding. As the core material, a UV cure epoxy resin was employed for ease of manufacturing. The refractive indexes and relative refractive index difference were determined so that bended propagation loss is within 0.01dB/cm at 850nm wavelength with radius of curvature of as small as 4mm. The relative refractive index difference between the core and the clad, determined on the bases of simulations and experiments, is 0.0148, which characterize the waveguide numerical aperture. Microlenses to allow wide alignment tolerance of optical elements and to reduce cross talks between channels are integrated into the waveguide by the injection molding process.

Fabrication of the base structure of the waveguide requires high degree of precision and careful processing, for which we used a metallic mold to achieve the accuracy and surface smoothness required for the 3-D optical path. The high precision injection molding produces precise end faces of the core grooves, and eliminates the necessity of end face polishing finish otherwise needed. Fabrication process flow is shown in Fig. 3.

The waveguide is passively aligned on the circuit board by image-recognition technology. The waveguide has a small tripod that serves as a pedestal to assure the precise gap distance between VCSELs/PIN PDs and microlenses integrated into the waveguide, and as a support to secure optical configuration integrity.



(a) Optical configuration (b) Cross section of the waveguide

Fig. 2 Basic Structure of the waveguide

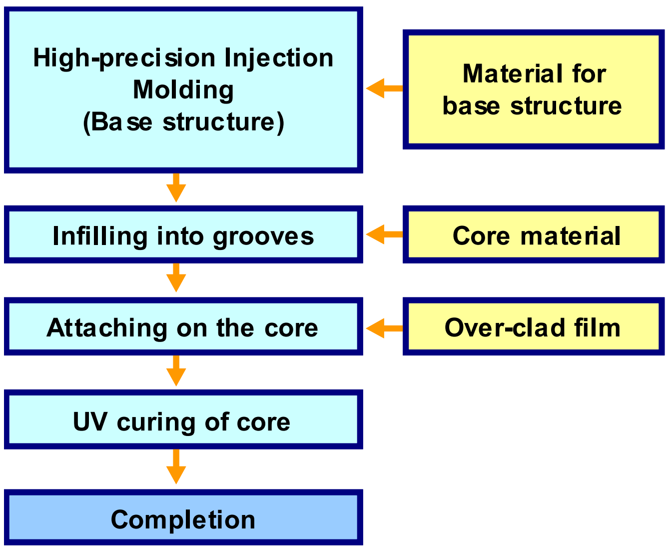


Fig. 3 Fablication process of the waveguide

3.3 Evaluation of the waveguide

Coupling losses and integrity or stability of the optical waveguide were subjected to evaluation tests. The characteristics of the waveguide we fabricated are summarized in Table 1.

Total optical loss of transmitting or receiving port was about 1.6 to 2.5dB including coupling loss between lens and guiding core. The waveguide was subjected to preliminary reliability tests of high temperature storage(85℃, 500hours) and high humidity test(45℃, 95%RH, 500hours). After initial changes due to stress relaxation, changes in loss that might cause practical problems were not observed, which indicates the cured core material stabilizes in a short period of time or aging process.

Table 1 Evaluation data

Actual measurement (Including coupling)

Total optical loss	**1.6 to 2.5 dB**

Breakdown of the total

Material loss	**0.1 dB**
Coupling loss	**0.9 dB**
Reflection loss	**0.4 dB**
Other loss	**0.2 to 1.1 dB**

3.4 Optical Parallel Transceiver using the 3-D waveguide

The 3-D waveguide was applied to an optical parallel link intended for use as an extender for copper cable links specified in 10GBASE-CX4, InfiniBand 4X, Fibre Channel standards. The targets are 3.125Gbps/lane 300m transmission with 850nm wavelength over the conventional multimode optical fiber. The 3-D waveguide we developed is used as an integral optical platform to which optical functions and components are integrated or assembled, which greatly simplified the optics assembly process implemented only by placing the waveguide on the circuit board on which VCSELs/PIN PDs, ICs and other electronic components are mounted. The use of the waveguide enabled mounting the VCSELs/PIN PDs, the ICs and high speed electric traces on a single small circuit board as shown in Fig. 4, which contributed to optimizing the high speed circuit design for future upgrade to 5Gbpb. The block diagram is shown in Fig. 5, and the outer view of the parallel transceiver is shown in Fig. 6.

Transceiver design features are as follows:

- Optical:
  - VCSEL(4-element array with 250μm spacing): 850nm-GaAs/AlGaAs Multi-Quantum Well laser with GaAs/AlGaAs DBR mirror, featuring high speed operation up to 5Gbps.
  - PIN PD (4-element array with 250μm spacing): GaAs PIN detector with an active area of 90μm.
  - Output interface: 12-channel MPO optical connector.
  - Power budget: Maximum output average power is -2.0dBm, and minimum receiving average power is -17dBm.

- Electrical:
  - The electrical interface: a high-speed differential copper connector compatible with MDI socket used in CX4, InfiniBand 4X, and Fibre Channel.
  - Circuit board design for high speed signal: optimized by making the best use of electromagnetic field simulations to reduce the degradation due to jitters and multiple reflections.
  - Hot pluggable.
- Mechanical:
  - Package size: equivalent to that of the industry standard MDI connector.
  - Right angled plug was developed and applied to allow space for mounting of the 3-D waveguide.

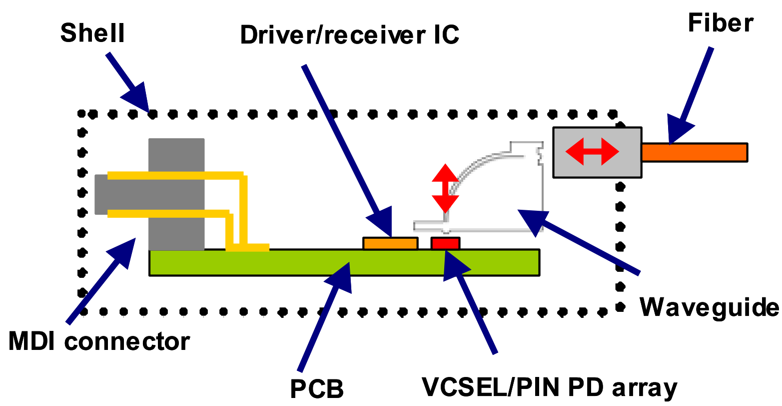


Fig. 4 Basic structure of parallel transciver

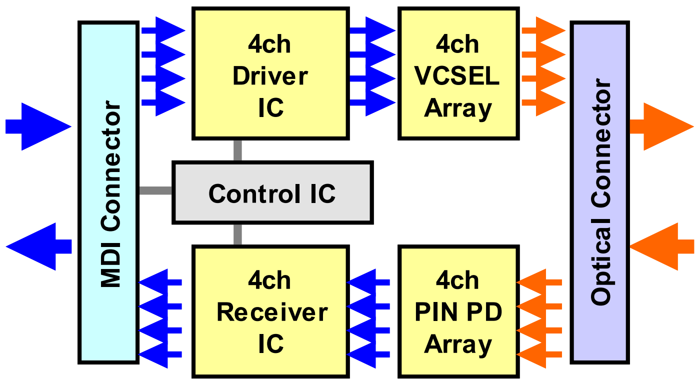


Fig. 5 Block diagram of the 4-channel parallel

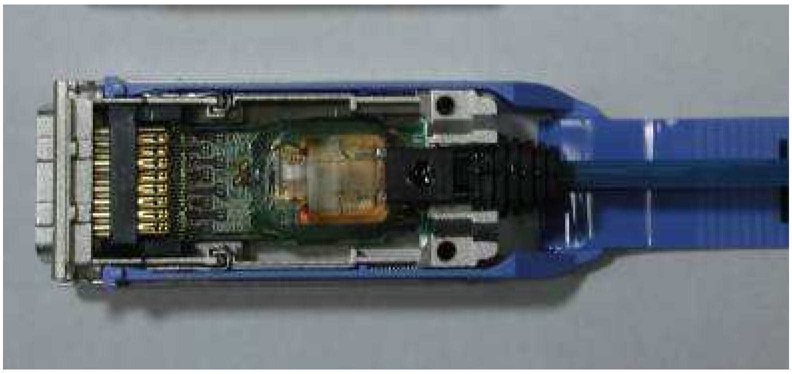


Fig. 6 Photograph of the parallel transceiver

3.5 Performance characteristics of the transceiver

The transmitter optical waveform with a fourth-order Bessel-Thomson filter is shown in Fig. 7. Excellent eye pattern openings were obtained at 2.5Gbps and 3.125Gbps with the extinction ratio of 6dB. Rise/fall time was less than 130ps and total jitter of each channel was about 60ps(p-p), far better than the design target of 100ps(p-p). The receiver electrical output waveform at 3.125Gbps is shown in Fig. 8. Sufficient eye height with total jitter less than 100ps was observed.

300m transmissions were successfully demonstrated at 3.125Gps and 2.5Gbps, with bit-error rate less than 10-12 over conventional multimode fiber. The minimum receiver sensitivity was measured to be better than -17dBm with all channels operated at bit error rate of less than 10-12. Sensitivity degradations due to optical and electrical cross talks between channels were not observed.

Power consumption is about 0.9w with 3.3V power supply. Operating case-temperature range is 0 to +70℃.

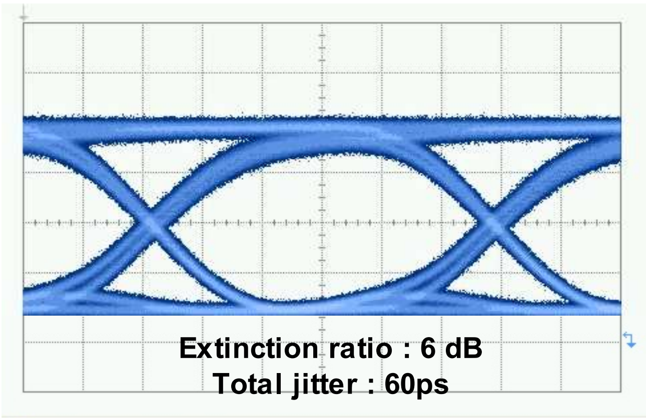


Fig. 7 Eye pattern of the optical output (3.125Gbps)

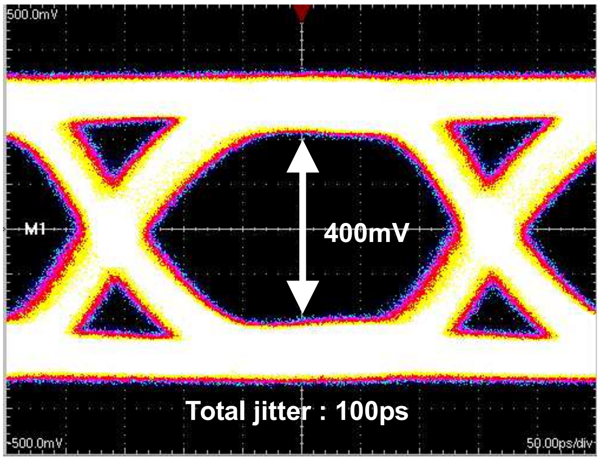


Fig. 8 Receiver eye pattern of the electrical output (3.125Gbps)

4 Conclusions

The 3-D waveguide we developed was successfully applied to a 4-channnel bi-directional parallel transceiver as an integral platform device to or around which optical devices and fibers are optically integrated or assembled.

The waveguide provides novel solutions to optical assembly implementation instead of conventional methods using discrete components spatially aligned to each other. The waveguide features scalability in both parallel (channel count) and functional integrations. The problems of the conventional discrete or hybrid optics are limitations in terms of compactness, coupling efficiency, and mechanical integrity which becomes increasingly difficult as the degree of parallel or functional integration gets larger, which are gracefully overcome by using 3-D waveguides. Therefore, the channel count can be easily increased to 12-channel bi-directional transceivers, or 12-channnel uni-directional transmitters or receivers as specified in SNAP12 MSA (Multi-Source Agreement).

The 4-channel transceiver developed is bit rate-transparent and application-agnostic, and can also be applied to SDR (2.5Gbps) InfiniBand 4X or Fibre Channel (3.1875Gbps) systems, in addition to 10GBASE-CX4. The use of the waveguide also increased flexiblity in circuit board design, which enabled mounting the planer optoelectronic devices, the ICs and high speed electric traces on a single board and contributed to optimizing the high speed circuit design for higher bit rates. The transceiver is easily upgradable to higher bit rates up to 5Gbps, or DDR (Double Data Rate) InfiniBand 4X. The VCSELs, PIN PDs we employed have a capability of operating at 5Gbps. Although the VCSEL driver and receiver ICs we now use are for 3Gbps operation, new versions that work at 5Gbps are becoming available with pin compatibility. Concerning bit rates above 5Gbps, the fundamental design is expected to be upgradable up to 10Gbps/lane speed by the use of emerging VCSELs and ICs for 10Gbps operation.

Revision	**Date**	**Changes**
Revision 0.1	Jun 9, 2006	Document creation.
Revision 0.2	Jun 13, 2006	Correction of page 2, item2.