OPTICAL ROUTER CORE SUBSYSTEM —AN ULTRA HIGH-SPEED OPTICAL LINE EXCHANGE EQUIPMENT

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We have developed a new type of ultra-high-speed optical line exchange equipment called the optical router core subsystem, which incorporates ultra-high-speed optical switching devices. This equipment offers ultra-high-speed bidirectional line exchange, enabling independent operation of optical modulation formats and bit rates. We have successfully demonstrated operation of this equipment in 43-Gbps DQPSK (Differential Quadrature Phase-Shift Keying), DPSK (Differential Phase-Shift Keying), and 160-Gbps RZ (Return to Zero) modulation formats without signal deterioration. This optical router core subsystem is expected to be applied to high-speed line switching in GMPLS (Generalized Multi-Protocol Label Switching), burst switches in optical networks, and interconnections of supercomputer nodes networks.

INTRODUCTION

Optical switching is a core technology in next-generation photonic networks, and optical switching devices are crucial equipment in the line switching part in next-generation optical routers. These devices must meet the following requirements:

(1) capable of switching optical routes within nanoseconds
(2) independent of wavelengths in wavelength division multiplexing (WDM) bands
(3) independent of optical modulation formats and communication speeds

Currently, a movable mirror, which is a kind of micro electro mechanical system (MEMS), is widely used for optical switching. This switch meets requirements (2) and (3), but its switching takes longer, i.e. as long as several milliseconds[1]. Semiconductor optical amplifier (SOA) gate switches and other switches which use optical crystals such as lanthanum-modified lead zirconate titanate (PLZT) have the advantage of high-speed operation within nanoseconds[2][3], but they have limitations in terms of wavelength and modulation format.

Yokogawa has developed a semiconductor optical switch which meets all three requirements, and has demonstrated that the switch changes optical routes within 2 nanoseconds and is independent of wavelength throughout the C band[4]. This device meets requirement (3) because it does not carry out any active operations such as amplification.
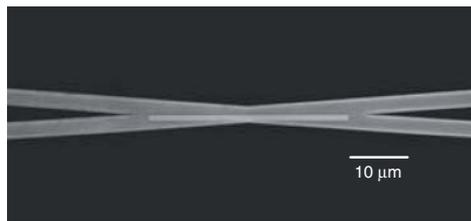
Figure 1 Crossover Portion of Waveguides in
Optical Switching Device (SEM)
(Width of each waveguide is 4 μm; cross angle is 5°)

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Table 1 Cross Angle of Waveguides and Changes of
Refractive Index in Its Critical Angles

2θ (°)	Δn (%)
2	−0.02
4	−0.04
6	−0.14
8	−0.24

(a) λ=1550 nm

(b) λ=1565 nm

(c) λ=1530 nm

Figure 3 Switching Time of Optical Switching Device

We have also developed ultra high-speed optical line exchange equipment incorporating the above-mentioned switching device, which we call an "optical router core subsystem." We built a prototype having 4 inputs and outputs (4 × 4) and externally-controlled optical switching devices. We verified that it transmits without deterioration 43-Gbps Differential Quadrature Phase-Shift Keying (DQPSK), Differential Phase-Shift Keying (DPSK), and 160-Gbps Return to Zero (RZ) signals, which are used in next-generation communications methods with both high speed and large capacity.

In this paper, we report on our ultra high-speed optical switching device, as well as the configuration and evaluation results of the optical router core subsystem.

OPTICAL SWITCHING DEVICE

Figure 1 shows the configuration of the optical switching device. Two planar waveguides are crossed on an indium phosphide (InP) substrate, and an electrode is provided at the crossover portion. A double heterostructure is employed in the cross section.
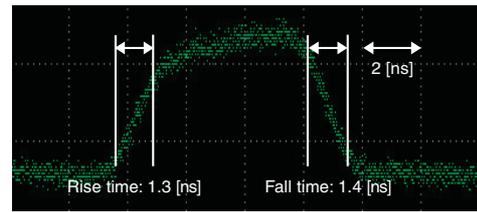
When current is injected, a high-density carrier layer is created beneath the electrode. This change of carrier density causes changes of the refractive index dew to the plasma dispersion effect. A sufficiently large change induces total reflection of light and thus switches the routes of optical signals. The relation among the change of refraction, Δn, the density of electrons, N, and the density of holes, P, is expressed by the equation[5]:

$$\Delta n = -\frac{e^2\lambda^2}{8\pi^2c^2\varepsilon_0 n}\left[\frac{N}{m_e}+\frac{P}{m_h}\right]$$
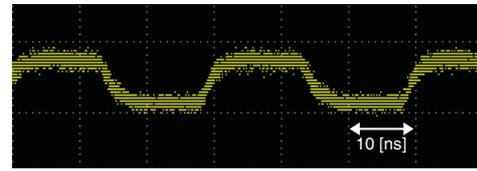
where, e is electron charge, m_e and m_h are effective mass of electron and hole, λ and c are wavelength and velocity of a light in vacuum, and ε_0 is the dielectric constant in vacuum. When the
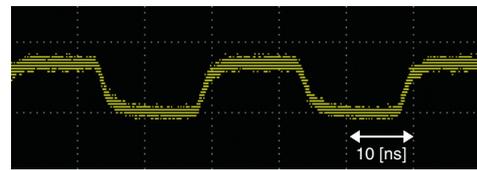
carrier density is about 1.0×10^{18}/cm³, the refractive index is expected to decrease by 0.1%.

Meanwhile, the change in refractive index necessary for total reflection in the waveguides at the cross angle of 2θ can be obtained according to Snell's law (Table 1). We set the cross angle at 4 to 8°. In such conditions, with the carrier density of 1.0×10^{18}/cm³ created by current injection, optical total reflection can be achieved. To verify it, we injected current of 150 mA into this device and confirmed the switching operation with an extinction ratio of about 15 dB.
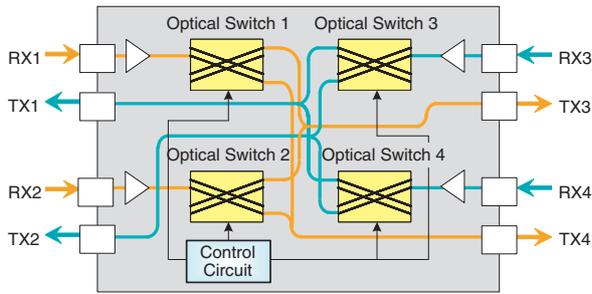
Figure 2 shows an implementation of the optical switching device. The device is equipped with input/output fibers and an electric input connector. To enhance performance, we made prototypes of 2 × 2, 4 × 4, and 6 × 6 switches and tested their operation. The 4 × 4 type is described below.

The switching time is 1.3 to 1.4 ns (Figure 3). This speed was confirmed to be independent of wavelength throughout the C band.

The loss of optical signals at the optical switching device is about 10 dB, most of which occurs at the connection between the waveguides and optical fibers. Changing the waveguide shape or

Figure 2 Implementation of Optical Switching Device

(a) Extinction ratio 15 dB   (b) Extinction ratio 25 dB
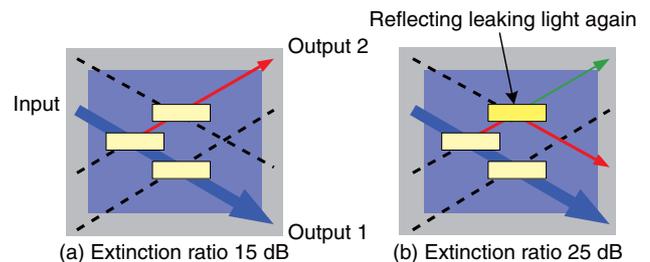
Figure 4 Improvement on Switching Device with 4 × 4 Switches

Figure 5 Configuration of Optical Router Core Subsystem

*1: Pulse Pattern Generator *4: Band Pass Filter
*2: Error Detector *5: Variable Optical Attenuator
*3: Amplified Spontaneous Emission

Figure 7 Evaluation System of 43-Gbps Optical Signals

implementation method would improve the results. Because the loss of optical signals in waveguides is small, i.e. 1 to 2 dB/cm, waveguides can be integrated multiple to improve the performance. For example, the device with 4 × 4 switches reflects leaking optical signals again and discards them into an unused port to improve the extinction ratio. Figure 4 shows such an improvement. The extinction ratio, which was 15 dB in 2 × 2 switches, was improved by this method to over 25 dB. This is an example of transmission operation, but extinction ratios of 25 dB or higher can also be obtained in reflection operation. The optical router core subsystem described here uses this type of switch.
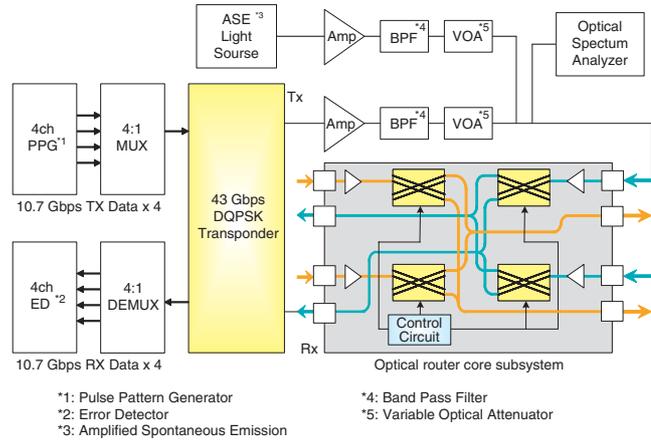
OPTICAL ROUTER CORE SUBSYSTEM

Configuration of optical router core subsystem

We have developed an optical router core subsystem which implements the optical switching device described in section 2, an optical amplifier, and a driver circuit in a single package and operates ultra high-speed optical line exchange in both directions. Figure 5 shows the circuit configuration and Figure 6 its external view. It has a port with 4 inputs and 4 outputs to bi-directionally exchange optical signals in two lines. Optical signals lost through the optical switching device are compensated at the optical amplifier, thus there is no attenuation of the signals.

Evaluation of characteristics of optical router core subsystem

To evaluate the characteristics, we measured the transmission characteristics and variation in phase shift of 43-Gbps DQPSK and DPSK signals (phase shift measurement was conducted with a phase modulation analyzer) and transmission characteristics of 160-Gbps RZ signals.
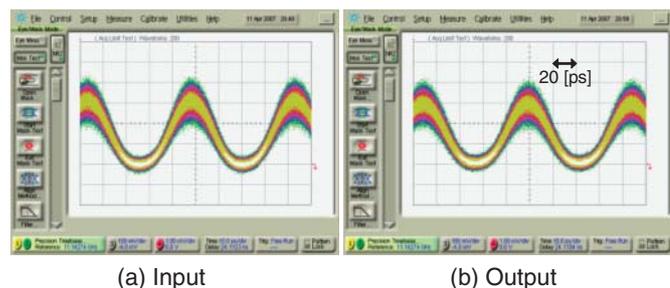
Transmission characteristics of 43-Gbps DQPSK and DPSK signals

43-Gbps DQPSK signals were transmitted through the optical router core subsystem, the waveform was observed, and the tolerance to optical signal-to-noise ratio (OSNR) was measured. Figure 7 shows the evaluation system, and Figures 8 and 9 show the results[6][7]. During the measurement, the optical switching device was not changed dynamically, the output port was set to the transmission side or reflection side, and each condition was measured.

The evaluation results show that deterioration of waveform was not observed. Tolerance to OSNR barely changed and the penalty was below 1 dB. Similar results were obtained in 43-Gbps DPSK signals: waveform and tolerance to OSNR were not changed.

Measurement of change characteristics of phase-shift keying modulated signals

Phases of DQPSK signals before and after transmission

Figure 6 External View of Optical Router Core Subsystem
(60 × 370 × 280 mm)

(a) Input　　　　(b) Output

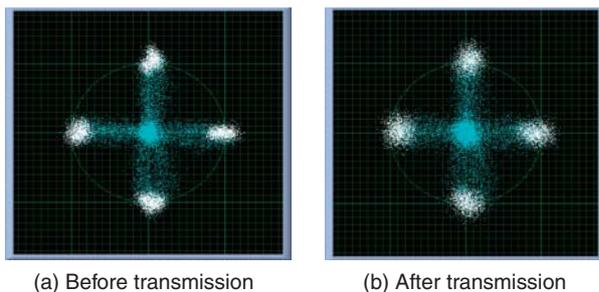**Figure 8** Transmission Characteristics of 43-Gbps DQPSK Signals
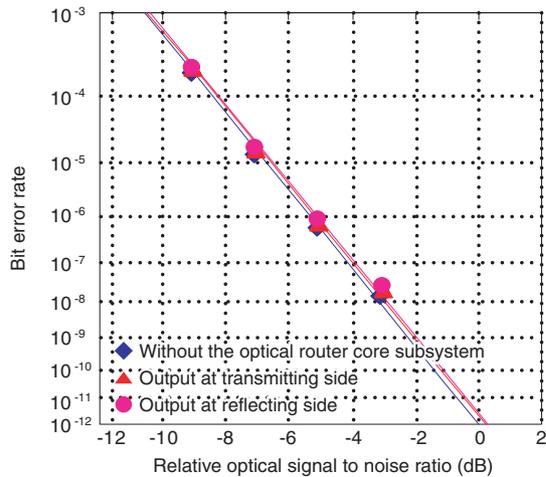
Figure 9 Relation between Bit Error Rate and OSNR
(The horizontal axis indicates relative OSNR to minimum receiving OSNR without the optical router core subsystem.)

through the subsystem were displayed on the I-Q plane by using a phase- modulation analyzer with a 1-bit delayed self-homodyne method, and their orthogonality was studied[8]. Figure 10 shows the results as a constellation diagram. Compared with the waveform before transmission, the waveform after transmission changed little. Thus, we confirmed that the orthogonality of In-phase and Quadrature-phase of 43-Gbps DQPSK signals is well preserved.
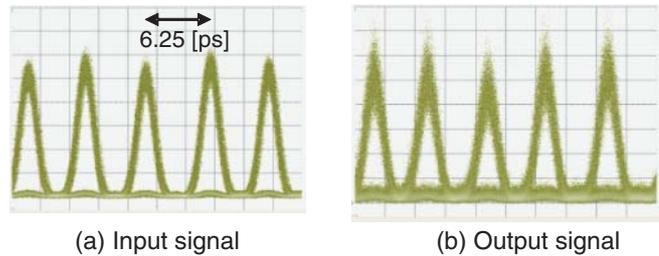
Transmission characteristics of ultra high-speed 160-Gbps RZ signals

160-Gbps RZ signals were transmitted through the optical switching device to confirm bit rate dependency.

Narrow sampling pulses created with a mode lock fiber laser were time-division multiplexed into 160-Gbps RZ Pseudo-Random Bit Sequence (PRBS) 2^7-1 signals. These were transmitted through the optical router core subsystem, and waveform output was observed with an optical sampling oscilloscope[9]. Figure 11 shows the waveform. Significant deterioration was not observed in the eye-diagram. Thus, this subsystem was confirmed to transmit 160-Gbps RZ signals.

(a) Before transmission   (b) After transmission

Figure 10 Constellation Diagram

(a) Input signal   (b) Output signal

Figure 11 Transmission Characteristics of 160-Gbps RZ signal

CONCLUSION

We have developed a new type of line exchange equipment, the optical router core subsystem, which incorporates an in-house optical switching device and carries out bidirectional ultra high-speed optical line switching. We verified that it operates independent of the modulation method and bit rate of optical signals, and this will be a key elemental technology in next-generation networks. This subsystem, implementing a high-speed trigger circuit or scheduling circuit, will be used for high-speed optical line exchange in GMPLS, optical burst switching networks, or communications among supercomputer nodes.

We are planning to develop networks applying this subsystem. ◆

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