Large-Capacity Optical Path Cross-Connect System for WDM Photonic Transport Network

Masafumi Koga, Member, IEEE, Atsushi Watanabe, Takeshi Kawai, Ken-ichi Sato, Senior Member, IEEE, and Yasuji Ohmori

Abstract—This paper demonstrates our recently developed large-capacity optical path cross-connect (OPXC) system. The major hurdles to be cleared are 1) establishment of a highly modular architecture that facilitates hardware design and upgrading and 2) development of an OPXC demonstrator designed to achieve 320-Gbit/s throughput capacity. Due to the use of planar lightwave circuit technologies, compact size packaging for an 8 × 16 delivery-and-coupling type optical switch and an arrayed-waveguide grating for a wavelength-demultiplexer are achieved. The dense packaging of the four-channel optical regenerators (3-R function regenerator) makes it possible to realize a large-capacity OPXC that can offer high quality transmission and ensure robustness in terms of multiple node connection. Performance test results confirm the validity of the system design and the feasibility of 320-Gbit/s OPXC implementation.

Index Terms—Optical cross-connect, optical switch, photonic transport network, wavelength division multiplexing (WDM).

I. INTRODUCTION

The growth of computer-based services and the progress of information transport technologies have gone hand in hand with a tremendous increase in content level on communication networks. One of the most popular computer-based services is the World Wide Web (WWW). After the WWW became popular in 1993, the number of users hooking up to the Internet increased tremendously. An Internet domain survey indicates that the number of Internet hosts was 15 million as of January 1997, up from 30,000 in December 1987 [1]. The number is projected to reach 100 million in 2000 [1], and the number of users will also increase exponentially. The result will be a traffic explosion with quantum leaps in transport network, wavelength division multiplexing (WDM). Necessary for realizing the optical path concept [5], [10]. Several projects/programs have been promoted worldwide to achieve the similar but slightly different goal of realizing a large capacity “all-optical” transport network. Examples include the ACTS project, MONET program, and NTONC [11]–[14]. ITU-T (International Telecommunication Union Telecommunication standardization sector) has also started a discussion in SG-13 on the optical transport network [15].

The development of a point-to-point WDM transmission system has been accelerated in the last few years, and an 8–16 WDM system is now commercially available [18]. Each channel has the capacity of 2.5 Gbit/s or 10 Gbit/s. The remaining major issue in hardware development is to realize a large-capacity wavelength router, the optical path cross-connect (OPXC) system.

The OPXC system is the key network element in realizing the optical path-based transport network. Three major hurdles exist on the road toward the realization of the large-capacity OPXC system. The three hurdles are: 1) establishing an effective architecture that facilitates hardware design and upgrading, 2) developing hardware, especially a compact size optical switch circuit, and 3) developing a simple monitoring system for supervision. We have recently cleared the first two hurdles and developed a large-capacity OPXC demonstrator, which was constructed on a highly modular and upgradable architecture [5].

This paper focuses on our activities toward hardware development for the large-capacity OPXC system. Section II summarizes the optical path concept and the SDH-based optical path transport networks that we aim to realize. Section III provides the OPXC system architecture and the results of hardware development. The architecture ensures expandability with respect to port number and wavelength. We have developed an OPXC demonstrator designed to achieve 320-Gbit/s throughput capacity. Section IV offers the performance test results of the developed OPXC demonstrator. In particular, the core optical component of the switch board is elaborated. Section V gives our conclusions on the development of a large-capacity OPXC system.

II. OPTICAL PATH NETWORK

The optical path network is characterized by the combination of WDM transmission and wavelength routing. Each optical path is carried by a WDM signal. Therefore, wave-
length routing means optical path routing utilizing an optical cross-connect system, and we call the wavelength router the optical path cross-connect. The optical path layer is a server layer for the SDH higher order path layer, and this concept offers several important characteristics for enhancing network potential [17].

Fig. 1 illustrates an example of optical path network application. The existing single-wavelength networks, for example, may correspond to regional transport networks while the optical path network acts as a nation wide backbone network. The optical path network is introduced by overlaying existing networks and is interconnected with existing networks. An optical line terminal (OLT) is placed on the inter-network connection point to terminate the optical path and offer an inter-network interface (INI). The optical path, which forms an optical section payload channel, is assigned between two OLT’s and has a TDM frame structure that retains maximum commonality with the SDH STM-N frame structure, as shown in Fig. 2. This TDM frame structure is defined as an optical container [17]. The optical container is composed of an optical path payload area with optical path overhead and an AU pointer area [17]. Thus, the optical path frame format is constructed based on the SDH frame format.

Electrical paths in any of several transfer formats can be accommodated in each optical path at the OLT whereby the optical path payload area maps SDH VC’s (virtual containers) which are supported as clients of the optical path. Various signal types, such as PDH signals, ATM cells, and IP packets, are mapped into the VC payload area, and the SDH-based optical path can carry the various signal types via VC’s [2]. These various signal data streams can be directly mapped into the optical path payload area. Thus, transfer format flexibility is attained by the optical path network and existing SDH terminating LSI’s can be exploited.

A network element connection model for optical path networks is depicted in Fig. 3 to explain the client/server relationship between electrical and optical paths. The electrical path trail is transported via-optical paths. Link connection of the electrical path is provided by a multiplex section (MS) trail in the single-wavelength SDH network and an optical path trail in the WDM optical path network. The INI at the OLT also provides quality of service (QoS, that is bit error rate) supervision and optical path connection management. These functions can be achieved by adopting the SDH-based optical path frame format [17]. When a failure occurs at some point along the optical path, the pair of OLT’s immediately switches the optical path for protection in the optical path layer according to the QoS or other control information. Thus the optical path network provides the following functions:

- transfer format flexibility;
- QoS supervision and connection management;
- optical path protection in the optical layer.

Here we emphasize that existing single-wavelength networks are not a part of the WDM-based optical path networks, although single optical path operation is possible in optical path networks.

The optical path network has the potential to offer significantly larger transport capacity than the existing single-wavelength network, owing to the WDM optical transmission technologies and the large capacity wavelength router potentially offered by the OPXC system. An 8–16 WDM transmission system has already developed to be commercially available [18]. Each optical path offers 2.5 Gbit/s or 10 Gbit/s to maximally exploit the cost benefits of WDM optical transmission. The remaining issue in hardware development is to realize the large-capacity wavelength router. The router throughput capacity is defined by the number of wavelength multiplexed, individual optical path capacity, and the number of fiber ports. OPXC system throughput capacity is summarized in Table I for nine sets of parameters. Our target in the first stage is to realize 160–320 Gbit/s capacity OPXC systems.

III. OPTICAL PATH CROSS-CONNECT SYSTEM

A. System Architecture

As we mentioned in Section II, the target in the first stage is a 160–320 Gbit/s OPXC system. The intention is to implement the 160–320 Gbit/s capacity OPXC system in a standard cabinet used by NTT.
The adopted OPXC system architecture that offers several hundreds of Gbit/s capacity per cabinet is shown in Fig. 4. Fig. 4 shows a 16 × 16 (incoming and outgoing) fiber-port OPXC system. The number of wavelengths, or optical paths, multiplexed on each fiber is eight. Each optical path has the capacity of 2.5 Gbit/s so the total system throughput is 8 × 16 × 2.5 Gbit/s = 320 Gbit/s. Details of optical path routing are described in [10].

The OPXC system is divided into three functional blocks: input high-speed interface, output high-speed interface, and cross-connect switch for optical path routing. The modular unit with which the system can be expanded consists of one of each of the three functional blocks. System expansion means increasing the number of fibers supported. The input high-speed interface consists of a pre-optical amplifier (Pre-OA), arrayed-waveguide grating (AWG) for wavelength-demultiplexing, and an optical regenerator at the electrical level (optical receiver/optical sender, Pre-OA: pre-optical amplifier, Post-OA: post-optical amplifier, OC: optical coupler).

In the wavelength path scheme [2], each OS is equipped with a laser source of a fixed wavelength. Although the so-called “all-optical” network can be constructed when we remove these OR’s/OS’s, the OPXC system cascadability would be strictly constrained [19]. The OR/OS approach is a practical way of ensuring OPXC system cascadability and realizing a nation wide backbone network. Simple regeneration (not including terminating LSI’s) will not be a significant part of total node cost [20]. Moreover, this architecture allows easy upgrading in terms of bit rate by simply using higher speed ORs/OS’s, and leaving the other blocks unchanged.
This system architecture offers high link optical switch modularity to allow the cost-effective deployment of OPXC systems at the early stage of introduction where traffic demands may warrant only limited equipment scale. This feature of high link modularity is due to the architecture of the cross-connect switch \[8\]. The architecture of the $8 \times 16$ cross-connect switch is shown in Fig. 5. The $8 \times 16$ cross-connect switch consists of multiple $1 \times 2$ switches and $16 \times 1$ combiners. This switch allows any of the eight incoming optical signals to be connected to any of the $16$ outgoing ports. It is possible for all channels to be cross connected to the same $8 \times 1$ combiner, if necessary. Owing to this switch configuration, the incoming $8 \times 16 = 128$ optical paths are cross-connected in a strictly nonblocking manner; here the network element operation system must ensure that wavelengths do not collide at output ports. This means that the switch is strictly nonblocking. We call this switch the delivery-and-coupling type optical switch (D&C-SW).

One important question is how to expand the level of wavelength multiplexing. Fig. 6 shows a modified architecture which promises wavelength expandability; it can support $16$ channel WDM transmission. The $16 \times 8$ D&C-SW is divided into two for one modular unit and the scale of the individual D&C-SW is $8 \times 8$. The number of fiber-ports decreases to eight so that the system can be implemented in NTT’s standard cabinet. Thus the total throughput is the same, $320$ Gbit/s, as that of the architecture shown in Fig. 4. The modular unit forms in one row, which is similar to the one shown in Fig. 4. When the demand for transmission capacity is low, an early stage, a system supervisor will implement one of the D&C-SW pairs and eight channel OR’s/O’S’s, corresponding to the wavelengths, $\lambda_1 - \lambda_8$, as shown in Fig. 6. In this eight wavelength case, the system total throughput is $160$ Gbit/s (= $8 \times 8 \times 2.5$ Gbit/s). Thus the modified architecture promises wavelength expandability in sets of eight channels, as well as fiber-port expandability. The wavelength multiplexing level can be increased to $24$ and to $32$, and further, if demanded. Note that advanced technologies for device integration and reduced power consumption are required to realize such $32$ WDM signal OPXC systems.

Network designer can choose either of the two architectures (Fig. 4 or 6) according to the introduction strategy and traffic demand.

\subsection*{B. Demonstrator Designed to Achieve 320-Gbit/s}

An OPXC demonstrator designed to achieve $320$ Gbit/s throughput capacity has been built on the architecture shown in Fig. 4. The appearance of the newly developed OPXC demonstrator is shown in Fig. 7. The demonstrator can accommodate $16$ modular units ($16$ input/output fibers); however, only four modular units and three extra $8 \times 16$ D&C-SW’s (seven $8 \times 16$ D&C-SW’s in total) were implemented for the performance test. Each modular unit consists of four different kinds of boards: Pre-OA with AWG board, OR/OS board (two boards for one modular unit), D&C-SW board, and post-OA with $16 \times 1$ optical combiner board. Thus, each modular unit is composed of five boards. The functional allocation to each board was optimized considering component size, maximum power consumption, and necessary number
of optical connectors, and so on. Each board has the area of 330 (W) × 300 (L) mm², which conforms to NTT’s standard fabric. The 8 × 16 D&C-SW board is 29 (H) mm high and other boards have a height of 9 (H) mm. This compact packaging of the optical switch is due to the PLC (planar lightwave circuit) technologies and multiple fibers (128 fiber lines) assemble technology adopted. The high density packaging with low power consumption is essential in realizing a large-capacity OPXC system.

Photographs of the D&C-SW board, pre-OA with AWG board, and OR/OS board that contains four pairs of OR/OS’s [the throughput of each board is 10 (= 2.5 × 4) Gbit/s] are also shown in Fig. 7. This high density packaging arrangement realizes a large-capacity OPXC system with high cost-effectiveness as well as simplicity. The compact packaging of the four-channel OR/OS in particular verifies that implementing the so-called “3-R function (reshaping, retiming, and regeneration)” on the OPXC system is practical. OR/OS accommodation offsets the loss of “all-optical” bitrate transparency by increased quality of transmission, cross-connect node cascadability, and robustness of the network. The network element management function (NEMF) shelf was not implemented, and a personal computer was used for switch control instead.

The system design details are listed in Table II. The transport distance between nodes is designed to realize over 120 km transmission with nonzero dispersion shifted fiber and no linear repeaters. This distance was confirmed in the performance test, as is discussed in Section IV. Expanding the transport distance by using multiple linear repeaters are discussed in detail in [23]. The wavelength spacing of 1 nm was designed before the course grid of 100 GHz was proposed in ITU-T [24].

IV. PERFORMANCE TEST

This section describes the tests performed to confirm D&C-SW optical performance, optical path switching, and system transport performance.

A. D&C-SW Optical Performance

The major D&C-SW optical performance is characterized by insertion loss and ON/OFF ratio. They were measured for
TABLE II
SYSTEM DESIGN DETAILS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal Speed (Optical Path Capacity)</td>
<td>2.5 Gbit/s</td>
</tr>
<tr>
<td>Multiplexed Wavelengths</td>
<td>8</td>
</tr>
<tr>
<td>Incoming/Outgoing Fiber Ports</td>
<td>16</td>
</tr>
<tr>
<td>Total System Throughput</td>
<td>320 Gbit/s</td>
</tr>
<tr>
<td>Wavelength Spacing</td>
<td>1 nm (1548–1555 nm)</td>
</tr>
<tr>
<td>Launched Output Power</td>
<td>&gt; 5 dBm/ch.</td>
</tr>
<tr>
<td>Minimum Received Power</td>
<td>&lt; -36 dBm/ch.</td>
</tr>
<tr>
<td>Distance Between Nodes</td>
<td>&gt; 120 km (No linear repeater)</td>
</tr>
</tbody>
</table>

![Histogram of fiber-to-fiber insertion loss](image1.png)

Fig. 8. Fiber-to-fiber insertion loss: (a) 8 × 16 D&C-SW board and (b) 8 × 8 D&C-SW board. $n$: the number of samples, $\mu$: average value, $\sigma$: standard deviation.

![Histogram of polarization-dependent loss](image2.png)

(a)

![Histogram of polarization-dependent loss with attenuation](image3.png)

(b)

Fig. 9. Polarization-dependent loss. (A) attenuation = 0 dB and (b) attenuation = 3 dB. The number of samples is 20.

The fabricated 8 × 16 and 8 × 8 D&C-SW boards described above. Histograms of the measured fiber-to-fiber insertion losses are shown in Fig. 8. Fig. 8(a) shows a histogram for a typical 8 × 16 D&C-SW board, while Fig. 8(b) is for an 8 × 8 board. Average insertion loss is seen to be 13 dB for each board. Since the insertion loss includes the 8 × 1 optical coupler loss of 9 dB plus excess loss of 1.5 dB and connector loss of 0.5 dB, the PLC switch loss is revealed to be only 2 dB for each bored.

The losses of optical components typically wander to some extent. Standard deviation of these boards is about 0.5 dB, assuming that the histogram statistically follows a Gaussian distribution, and the measured insertion losses range from 11.5 to 14 dB. The optical components create deviation in the power levels of the channels which limits possible transport distance.

The optical power deviation can be adjusted by the gate switches in this board. Each gate switch consists of an asymmetrical Mach–Zehnder interferometer (MZI) with thermooptic phase shifter. Attenuating the MZI output power makes it possible to make the deviation uniform. The adjustment range is designed to be 3 dB.

As the MZI attenuates the output power, the polarization dependent loss (PDL) generally increases. The PDL in the MZI arises from polarization dependencies of the coupling efficiency of the 3 dB couplers in the MZI and its thermooptic oriented phase difference. The MZI PDL was measured for several ports, sampled at random, at attenuation values of 0 dB and 3 dB. Fig. 9 shows the 8 × 16 D&C-SW board measurement results for fiber-to-fiber PDL. Fig. 9(a) shows the histogram for the attenuation of 0 dB, while Fig. 9(b) shows that for the attenuation of 3 dB. The maximum PDL is 0.6 and 0.7 dB, respectively. Note that these measured values include the error of optical connector setting of about 0.2 dB. The increase in PDL with the attenuation of 3 dB is only 0.1–0.2 dB. Given that the adjustment range is 3 dB, the PDL will have negligible impact on optical signal transportation.

ON/OFF ratio of the cross-connect switches is one of the most important properties in the OPXC system. Optical
leakage power due to insufficient ON/OFF ratio interferes with the optical signals and causes bit-errors. As the number of incoming/outgoing fibers increases, optical leakage signals accumulate and the leakage power increases. Thus a large ON/OFF ratio is required for a large capacity OPXC system.

The required ON/OFF ratio is $40 \text{ dB}$ in the case of a $16 \times 16$ fiber port OPXC system [10]. For an $8 \times 8$ port OPXC system, the ON/OFF ratio requirement can be relaxed to $>37 \text{ dB}$ since the accumulation in leakage optical power becomes half. Taking into account the adjustment range of $3 \text{ dB}$ in the ON state, the value of $3 \text{ dB}$ is added to the ON/OFF ratio requirement; $>43 \text{ dB}$ for the $16 \times 16$ OPXC system and $>40 \text{ dB}$ for the $8 \times 8$ OPXC system.

The measured ON/OFF ratios are shown in Fig. 10. Fig. 10(a) shows a histogram for one $8 \times 16$ D&C-SW board, while (b) shows that for an $8 \times 8$ D&C-SW board. Average ON/OFF ratio is $58$ and $48 \text{ dB}$ for the $8 \times 16$ and $8 \times 8$ D&C-SW board, respectively. The ON/OFF ratio has been clearly improved from the former report (see [10]) by eliminating process error. Although several samples still fail to achieve the required values, a sufficient QoS on signal transportation can be offered since the accumulation level satisfies the requirement. To attain the completeness, a novel PLC process technology is needed and is now being under way. Note that the ON/OFF ratio was measured for all combinations of input and output ports, and the number of samples was $8$ (input channels) $\times 15$ (leakage channels) $\times 16$ (ON state channels) $= 1920$ for $8 \times 16$ D&C-SW board, and is $8$ (input channels) $\times 7$ (leakage channels) $\times 8$ (ON state channels) $= 448$ for the $8 \times 8$ D&C-SW board.

The D&C-SW boards exhibited excellent temperature stability even though switching involves thermo-optic effects. Fig. 11 shows an example of the stability of output optical power level when atmospheric temperature varied from $5$ to $65^\circ \text{C}$. It can be seen that both ON and OFF state output power levels are very stable, within $1 \text{ dB}$, and the ON/OFF ratio exceeded $50 \text{ dB}$ during a $7.5 \text{ h}$ short-term test.

**B. Cross-Connect Operation**

The optical path cross-connection time is another of the major parameters determining the performance of optical path restoration and network reconfiguration in the optical path based network. The optical path settling time for all optical paths in the OPXC system should be less than $10 \text{ ms}$ [25].

The optical path switching performance of an $8 \times 8$ D&C-SW board implemented with a microprocessor was tested. The microprocessor communicates with an external personal computer which simulates a network element function. When an optical path network is reconfigured for some event, the necessary Gate-SW’s in the OPXC system are closed so that optical power transients cannot be transferred to the next node. After that, the destination port of the optical path is set by $1 \times 2$ switches and immediately the closed Gate-SW’s open.

The simple model of optical path switching used for simulating network reconfiguration is depicted in Fig. 12. Two optical paths of wavelength $\lambda_1$, pass through the OPXC. Path 1 is initially set to destination port #1 in D&C-SW #1 while...
Fig. 12. Optical path switching operation.

Path_2 is set to Port #2 in D&C-SW #2. The two optical paths are exchanged in the following procedure: 1) turn off Gate-SW #1 in D&C-SW #1 and Gate-SW #9 in D&C-SW #2, 2) set the appropriate 1 × 2 SW’s, and 3) turn on Gate-SW #9 in D&C-SW #2 and Gate-SW #1 in D&C-SW #2. Gate-SW’s #1 and #9 should be closed so as not to transmit transient optical power while setting the 1 × 2 SW’s. The optical path exchange was observed at output port #1 and #2 in D&C-SW #1, and the result is shown in Fig. 13. Gate-SW rise and fall times (10–90%) are about 2 ms. The Gate-SW close time from turn off to turn on was set to be 2 ms. Thus the total optical path settling time was found to be about 4 ms.

Note that the Gate-SW rise time of about 2 ms is also effective to suppress optical surge in the cascaded Post-OA and linear repeaters, because this rise time is longer than the transient effects of gain saturation and recovery which typically occur on a 100 μsec — 1 ms time scale in erbium-doped optical amplifiers [21].

Fig. 13. Switching result. Gate-SW close time was set to be 2 ms.

C. Transport Experiment

Transport performance was tested by setting up a connection from origin to termination nodes via a 4 × 4 cross-connect node. The demonstrator implemented with four modular units as shown in Fig. 7, was used as the 4 × 4 cross-connect node. The test setup is shown in Fig. 14. Eight WDM signals were launched from the origin node into a 100 km nonzero dispersion shifted fiber (NZ-DSF). At the OPXC the WDM signals were split into four fibers. A total of 32 (8 WDM signals × 4 incoming fibers) optical paths were cross-connected in the 4 × 4 cross-connect node. After cross-connection, eight of the 32 optical paths were passed to the termination node through a 160 km NZ-DSF. Thus the overall transport distance was over 260 km. The NZ-DSF zero dispersion wavelength was about 1522 nm.

The optical spectrum of each cross-connected signal was observed. Examples of the observed spectra are shown in Fig. 15(a). The upper two figures show the spectra for the optical signals from two (#2 and #4) of the four D&C-SW boards, connected to outgoing fiber #1 (see Fig. 14). Optical signal levels were adjusted to —11 dBm, and leakage signals...
The bit-error rate (BER) was measured for all cross-connected signals. The test results are shown in Fig. 15(b). Error-free transmission was confirmed, although the receiver sensitivity diverges by 3 dB. The inferiority of channels 1 and 2 is mainly due to the poor drive circuit performance of the laser sources. The slight sensitivity divergence stems from the gain tilt of the Post-OA and the nonuniform noise figures of the Pre-OA’s. A longer transport distance can be attained by utilizing multiple linear repeaters [23].

These performance test results confirm the validity of our design and the feasibility of the large-capacity optical path cross-connect system. A simple supervisory system remains to be developed. Supervisory systems for the optical path layer (that is called as optical channel layer in ITU-T [15]), optical multiplex section, and optical transmission section must be developed hand in hand with the operation administration and management system.

V. CONCLUSION

This paper presents our hardware development activities for the optical path cross-connect system. An optical path cross-connect demonstrator, designed to achieve 320-Gbit/s throughput capacity (an 80-Gbit/s stage was implemented for the experiments), has been developed. The developed OPXC demonstrator is a milestone toward the realization of optical path based photonic transport networks. Owing to the planar lightwave circuit technologies and multiple fiber assembly technology adopted, the core component, an 8 × 16 DC-SW, could be packaged on NTT’s standard board. The four-channel OR’s/OS’s, which offer compact packaging, offset the loss of “all-optical” bit rate transparency by improved quality of transmission, node cascadability, and robustness of the network. Performance tests confirmed the design validity of the system, and thus the feasibility of the 320-Gbit/s optical path cross-connect system.

The development of a simple supervisor system is a challenge. The supervisory system must be developed hand in hand with the operation system. We need to accelerate discussion of operation, administration, and maintenance matters.

ACKNOWLEDGMENT

The authors would like to express their appreciation to Dr. M. Okuno and Dr. H. Takahashi for their support and cooperation regarding planar lightwave circuits.

REFERENCES

Masafumi Koga (M’89) was born in Fukuoka, Japan, on February 14, 1959. He received the B.E. and M.E. degrees in electronics engineering from the Kyushu Institute of Technology, Fukuoka, in 1981 and 1983, respectively, and received the Dr.Eng. degree from Osaka University, Osaka, in 1993.

In 1983, he joined the NTT Electrical Communications Laboratories, Yokosuka-shi, Japan, where, from 1986–1992, he has been mainly engaged in the research of optical signal processing technologies including optical circulators and their functional circuits. Since 1994, he has been designing and developing a hardware system for realizing the photonic transport network. Dr. Koga is a member of the Institute of Electronics, Information, and Communication Engineers (IEICE) of Japan.

Ken-ichi Sato (M’87–SM’95) for a photograph and biography, see this issue, p. 994.

Dr. Watanabe received the Young Engineer Award in 1997 from the Institute of Electronics, Information, and Communication Engineers (IEICE) of Japan. He is a member of the IEICE of Japan.

Yasuji Ohmori was born in Siga, Japan, on October 20, 1949. He received the B.S. degree in physics from Tohoku University, Japan, in 1974 and the M.S. degree in physics from Tokyo University, Japan, in 1976. He received the Ph.D. degree in electronics engineering from Tokyo University, Japan, in 1985.

In 1976, he joined NTT Ibaraki Electrical Communication Laboratories, Ibaraki-ken, Japan, where he was engaged in research on optical fibers. He is now with NTT Opto-electronics Laboratories and is engaged in research on optical waveguides and guided-wave optical devices.

Dr. Ohmori is a member of the Institute of Electronics, Information, and Communication Engineers (IEICE) of Japan and the Japan Society of Applied Physics.