Extended Optical Fiber Line Testing System Using New Eight-Channel L/U-Band Crossed Optical Waveguide Coupler for L-Band WDM Transmission

Noriyuki Araki, Hisashi Izumita, *Associate Member, IEEE, Member, OSA*, Nazuki Honda, and Minoru Nakamura

***Abstract*—This paper describes the system design for an extended optical fiber line testing system that uses a new L/U-band crossed optical waveguide coupler and a fiber Bragg grating filter for L-band wavelength-division multiplexing transmission. We describe the reflection characteristic required for optical filters located in central offices in order to suppress the ghost signal caused by multireflection in the optical time-domain reflectometry (OTDR) trace. We design and evaluate an eight-channel crossed optical waveguide coupler with a new thin dielectric film filter that separates a 1650-nm test light from the L-band communication light, and confirm that there was no degradation caused by multireflections in the OTDR trace. We also demonstrate the in-service line monitoring of a 10-Gb/s L-band transmission with no degradation in the transmission quality.**

***Index Terms*—Maintenance, optical couplers, optical fiber testing, optical filters, optical time-domain reflectometry (OTDR), optical waveguide components, wavelength-division multiplexing (WDM).**

I. INTRODUCTION

IN the fiber-to-the-home (FTTH) era, it is expected that broadband network provision will require thousands of optical fibers to be accommodated in a central office for optical access networks [1]–[4]. An optical fiber line testing system is essential for reducing maintenance costs and improving service reliability in optical fiber networks. We have already developed such a system called AURORA (automatic Optical Fiber Operations Support System) [5]–[8]. Recently, a long wavelength band (L-band) that extends to 1625 nm has begun to be used for wavelength-division multiplexing (WDM) transmission [9]–[11], and a 10-Gb/s WDM system is being introduced into metropolitan networks [12]. As we already use the 1310- and 1550-nm wavelengths for such communication services as ATM-PON and CATV [13], we use the 1650-nm wavelength for maintenance testing [8], [14] in accordance with ITU-T Recommendation L.41 [15]. With a view to monitoring optical fibers transmitting L-band communication light, an attractive way of separating the 1650-nm test light from the L-band communication light is to use a chirped fiber Bragg grating (FBG) filter because of its steep optical spectrum [8]. However, it is difficult to measure fiber characteristics accurately using an optical time-domain reflectometer (OTDR) because multireflections appear in the OTDR trace when FBG filters are installed at either end of an optical fiber line.

In this paper, we describe the design of the reflection characteristic required for optical filters located in central offices in order to suppress these multireflections. We propose an extended optical fiber line testing system that employs a new L/U-band crossed optical waveguide coupler in a planar lightwave circuit (PLC) with a multiarray design. We also demonstrate the in-service line testing of a 10-Gb/s L-band transmission.

II. SYSTEM CONFIGURATION OF EXTENDED AURORA

Fig. 1 shows the system configuration of extended AURORA. This system consists of a control terminal; a test equipment module (TEM), which contains an OTDR and a test control unit (TC); optical fiber selectors (FS) that select fibers to be tested; test access modules (TAM) to introduce a test light into an optical fiber line; and termination cables with an optical filter that allows a communication light to pass but not a test light. The OTDR test wavelength is 1650 nm, which is different from the communication light wavelength. This means that the system can perform maintenance tests on in-service fibers with no degradation in the transmission quality [5], [8]. The control terminal, which is located in a facility maintenance center for outside plant, orders various optical fiber tests and administers fiber information. TEMs, fiber termination modules (FTMs), and integrated distribution modules (IDMs) [4], which house TAMs and FSs, are installed in a central office. Termination cables with filters are positioned in front of the termination equipment (e.g., ONU or RT) on the user's premises. The various commands from the control terminal to the TEMs are transmitted through a data communication network (DCN). In order to apply this system to L-band WDM transmission, the optical characteristic of the filters in the TAM and the termination cable must be extended to the L-band.

III. DESIGN OF L/U-BAND OPTICAL FILTER APPLIED TO EXTENDED AURORA

The FBG filter has a considerable advantage in that its steep optical spectrum allows L-band communication light to pass while cutting off the 1650-nm test light, and this filter is already

Manuscript received February 25, 2003; revised August 12, 2003.
The authors are with NTT Access Network Service Systems Laboratories, NTT Corporation, Tsukuba-city, 305-0805 Ibaraki, Japan (e-mail: noriyuki@ansl.ntt.co.jp).
Digital Object Identifier 10.1109/JLT.2003.821761

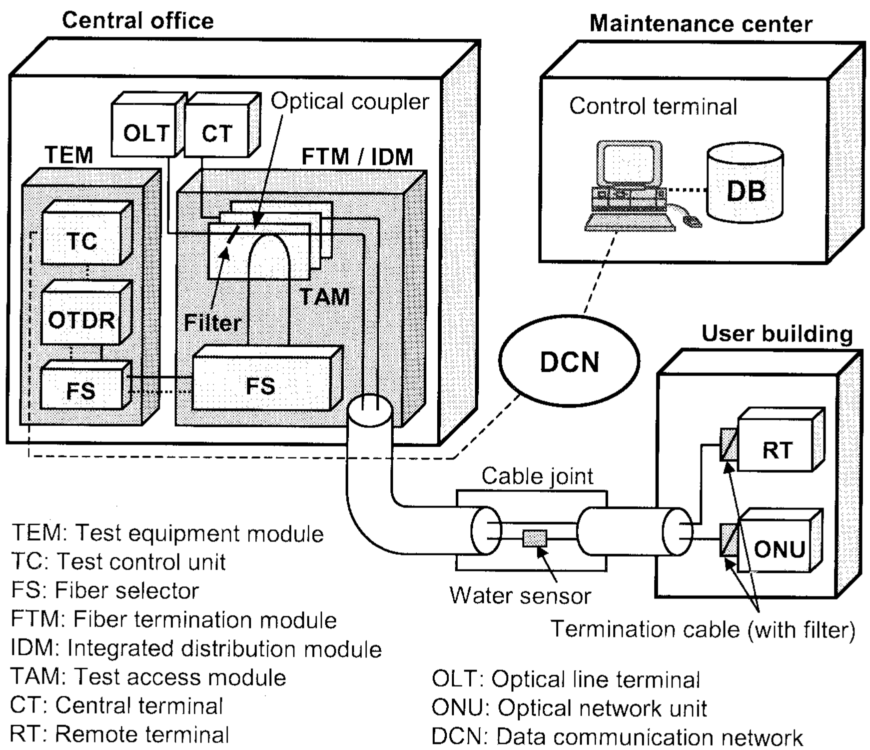


Fig. 1. System configuration of extended AURORA.

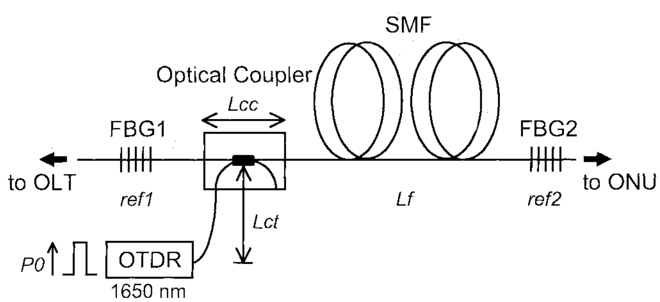


Fig. 2. OTDR test setup with FBG filters at either end of optical fiber line.

used in termination cable [8]. However, multireflections appear in the OTDR trace when FBG filters are installed at either end of the optical fiber line, because the OTDR test light pulses are strongly reflected at the FBG filters.

A. Multireflection in OTDR Trace Using FBG Filters at Either End of Optical Fiber Line

Fig. 2 shows our experimental OTDR test setup with FBG filters at either end. We incorporated an optical coupler in the optical fiber line with which to introduce the test light. The coupling ratio of the optical coupler was designed to be 80:20. The transmission and test port insertion losses (Lct and Lcc) were 1.95 and 7.84 dB, respectively. The test light wavelength of the OTDR was 1650.1 nm with a full-width at half-maximum of 0.2 nm. We positioned FBG filters at either end of the optical fiber line to cut off the test light. The return losses of FBG1 and FBG2 were 0.4 and 0.3 dB, respectively, in the 1650-nm band. The test fiber was a 4.54-km-long conventional single-mode fiber (SMF), and the fiber loss in the 1650-nm band was 1.4 dB.

Fig. 3 shows the OTDR trace we obtained using the experimental setup shown in Fig. 2. The pulse width, pulse period, and measured distance range of the OTDR were 1 μs, 120 μs, and 5 km, respectively. There are three ghost signals at 1.2, 2.4, and 3.6 km in the OTDR trace. These ghost signals degrade the accuracy of the OTDR measurement.

The location of the ghost signal that appears in the OTDR trace depends on the difference between the OTDR pulse period and the multireflection period. The Nth round-trip transit time, which is the time taken by an OTDR pulse to reach the far end of an optical fiber and return to the input end $T_{\text{ref}}(N)$, is given by

$$T_{\text{ref}}(N) = \frac{2nD_f(N+1)}{c} \tag{1}$$

where n is the group index of the optical fiber, D_f is the length of the optical fiber, and c is the speed of light in a vacuum. Therefore, the location of the ghost signal caused by the Nth reflection, $D_{\text{ref}}(N)$ is expressed as

$$D_{\text{ref}}(N) = \frac{c(T_{\text{ref}}(N) - Tp \times M)}{2n}, \quad \left(M = \text{Integer}\left[\frac{T_{\text{ref}}(N)}{Tp}\right]\right) \tag{2}$$

where Tp is the incident OTDR pulse period. When $D_{\text{ref}}(N)$ is less than the length of the measured distance range, the Nth reflection originating from the OTDR pulse is superimposed at a distance of $D_{\text{ref}}(N)$ [m] in the OTDR trace as a ghost signal.

In our experimental setup, the parameters were $n = 1.45$, $D_f = 4.54$ [km], and $Tp = 120$ [μs]. The locations of the ghost signals caused by the second reflection $D_{\text{ref}}(2)$, the fifth reflection, $D_{\text{ref}}(5)$, and the eighth reflection $D_{\text{ref}}(8)$, calculated

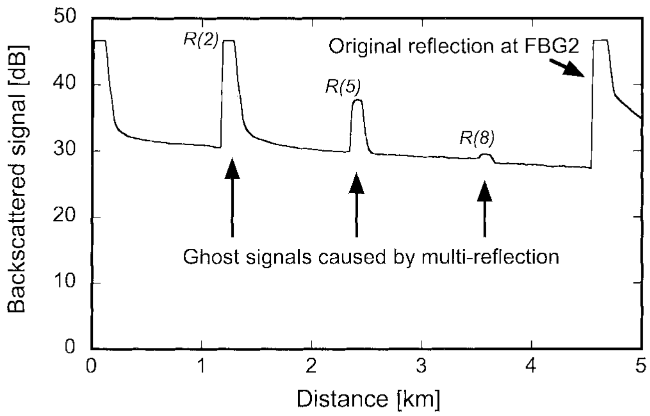


Fig. 3. Experimental OTDR trace with multireflections.

using (1) and (2), were 1.2, 2.4, and 3.6 km, respectively, in the OTDR trace. These results correspond to the experimentally obtained OTDR trace seen in Fig. 3.

An effective to cope with the ghost signals caused by multireflections is to design the incident pulse period so that it is long enough for the multireflected pulse to be attenuated by the loss of the optical line and become negligible. However, it takes a long time to test an optical fiber line using this approach and it degrades the performance of the optical fiber line testing system, which accommodates several thousand optical fibers. Therefore, we propose a method whereby one of the two optical filters installed at either end of the optical fiber line has a high return loss to attenuate the multireflected pulse.

B. Design of Optical Filter in Central Office

To suppress the ghost signal, we can design the optical characteristic required for the optical filter in the central office as follows. The minimum Rayleigh backscattered signal power in a measured OTDR trace is that which originates at the fiber end. Therefore, the power of the ghost signal, which is the incident OTDR pulse after the Nth round-trip (Nth reflection) $R(N)$, should be sufficiently lower than the Rayleigh backscattered signal power from the fiber section adjacent to the FBG2 filter Pr. Pr and $R(N)$ are given by (3) and (4), respectively

$$Pr = P0 - Lct - Lf + Bs \tag{3}$$

$$R(N) = (P0 - Lct - Lf - \text{ref2}) - (2Lf + 2Lcc + \text{ref1} + \text{ref2}) \times N, \quad (N = 0, 1, 2, \ldots). \tag{4}$$

Here, the return losses of FBG1 and FBG2 are ref1 [dB] and ref2 [dB], respectively, the fiber loss is Lf [dB], the optical coupler insertion loss of the test and communication ports is Lct [dB] and Lcc [dB], respectively, the peak power of the optical pulse from the OTDR is $P0$ [dBm], and the Rayleigh backscattering coefficient with the test light wavelength is Bs [dB].

If $R(N)$ is sufficiently lower than Pr, the ghost signal in the OTDR trace is negligible. The difference between Pr and $R(N)$ is derived from (3) and (4)

$$Pr - R(N) = Bs + 2N \times Lf + 2N \times Lcc + N \times \text{ref1} + (N+1) \times \text{ref2}, \; (N = 0, 1, 2, \ldots). \tag{5}$$

A conventional OTDR launches an optical pulse into a test fiber with a period of more than twice the delay, which corresponds to the transit time needed for the optical pulse to make a round-trip of a fiber length equal to the distance range. Therefore, the power of the ghost signal that originated from the secondary reflection $R(2)$ is larger than any other high-order ghost signal power. Consequently, when $R(2)$ is sufficiently lower than Pr, the ghost signal caused by multireflection in the OTDR trace is negligible.

The difference between Pr and $R(2)$ is derived from (5)

$$Pr - R(2) = Bs + 4Lf + 4Lcc + 2\text{ref1} + 3\text{ref2}, \text{ for } N = 2. \tag{6}$$

The OTDR trace near the lower limit of the measured dynamic range has a conspicuous fluctuation that is mainly caused by thermal noise, and this fluctuation degrades the OTDR measurement accuracy. The fluctuation in the OTDR trace depends on the signal-to-noise ratio (SNR) at that point [16]. For example, when the noise level is defined as rms (SNR $=$ 1), the OTDR trace located 5 dB higher than the noise level has a fluctuation of 0.2 dB compared with the true OTDR trace. Here, if we regard the ghost signal power as a sort of noise in the OTDR trace, in order to reduce the fluctuation caused by the ghost signal in the OTDR trace to less than 0.2 dB, the secondary reflection power $R(2)$ must be 10 dB less than the Rayleigh backscattered signal $Pr : Pr - R(2) > 10$ [dB].

Under this condition, the required return loss of the optical filter in the central office ref1 is described by (7).

$$\begin{aligned} \text{ref1} &> 5 - \frac{Bs}{2} - 2Lf - 2Lcc - \frac{3\text{ref2}}{2} \\ &> 5 - \frac{Bs}{2} - 2Lcc - \frac{3\text{ref2}}{2} \end{aligned} \tag{7}$$

Taking any fiber loss of Lf that is more than 0 dB into consideration, the required return loss is decided as a function of the Rayleigh backscattering coefficient Bs, the insertion loss of the optical coupler Lcc, and the return loss of the FBG2 filter located at the far end of the optical fiber line ref2.

IV. New Eight-Channel L/U-Band Crossed Optical Waveguide Coupler

In accordance with the above design for the optical filter in a central office, we developed a new L/U-band filtering technology with a high return loss using a crossed optical waveguide coupler with thin dielectric film. This is based on planar lightwave circuit (PLC) technology [17]. Multiarrayed circuits can be fabricated on a PLC chip and one dielectric film filter can be incorporated in the groove that traverses the crosspoints of the crossed optical waveguide couplers.

A. Design of Insertion Loss Spectrum of Dielectric Film Filter

Fig. 4 shows the insertion loss spectra of a conventional optical filter designed to eliminate a 1650-nm-band test light and our new optical filter, which allows L-band light to pass but not the 1650-nm-band light. The cutoff band of the conventional optical filter starts at about 1600 nm, and the insertion loss at 1625 nm is 39.7 dB. To reduce the insertion loss at the L-band wavelength, we designed and developed a new thin dielectric

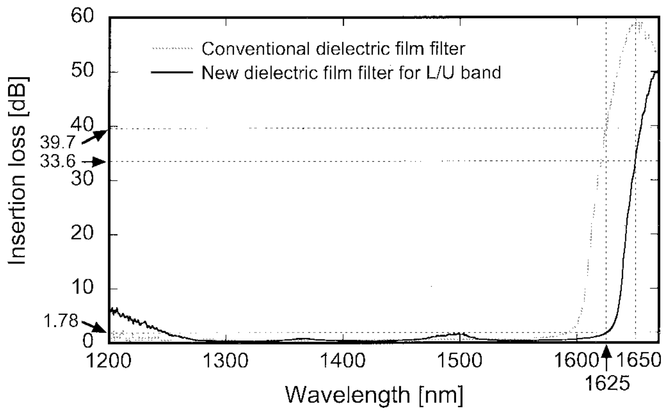


Fig. 4. Insertion loss spectra of conventional dielectric film filter and new filter for L/U band.

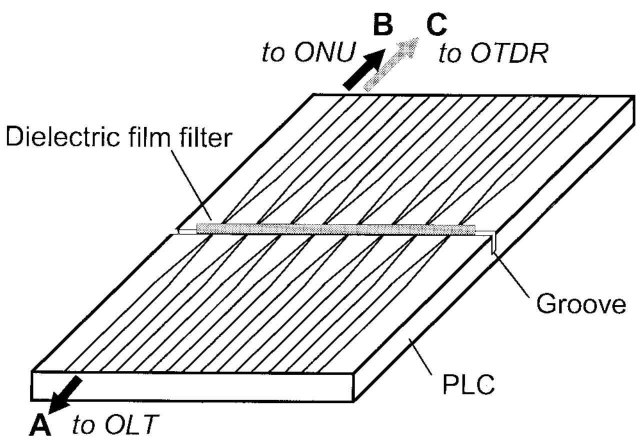


Fig. 5. Structure of eight-channel crossed optical waveguide coupler.

film filter that consists of alternating Ta_2O_5/SiO_2 multilayers on a polyimide-based film by using the ion-assisted deposition (IAD) method [18]. The thickness and number of the deposited layers that constitute this filter are 32 μm and about 100, respectively. The insertion losses of the new optical filter at 1625 and 1650 nm are 1.78 and 33.6 dB, respectively.

B. Configuration and Design of New Crossed Optical Waveguide Coupler

Fig. 5 shows our new TAM structure consisting of eight crossed optical waveguide coupler arrays that we integrated on a 4×20 mm chip. We adopted a silica waveguide with a core/cladding refractive index contrast Δ of 0.45% and a core size of 7×7 μm^2. Our new dielectric film filter, which separates the 1650-nm test light from the L-band communication light, was inserted in the groove at the crosspoint of two waveguides on the PLC. The groove was 200 μm deep and 40 μm wide, and its cross-section was perpendicular to the waveguide surface. We designed the insertion angle of the filter at 6° to the waveguides. Each waveguide was arrayed with a 127-μm spacing at either facet of the chip to provide compatibility with layered standard single-mode eight-fiber ribbons.

Port A to port B is used as a communication line. A 1650-nm test light introduced from port C is reflected by the dielectric film filter and input into the fiber line via port B. The L/U-band

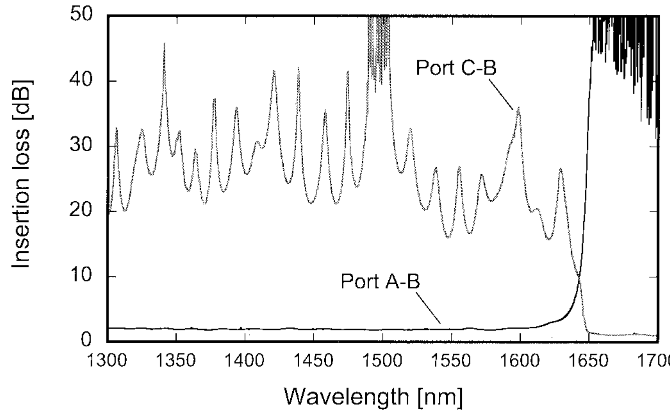


Fig. 6. Insertion loss spectra of crossed optical waveguide coupler.

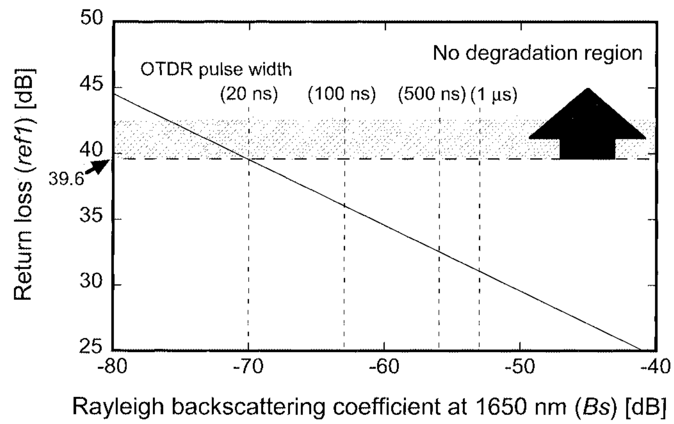


Fig. 7. Required return loss of TAM.

filter can be shared by the eight-channel ports and is not required to collimate the optical coupling between the filter and the waveguides. Therefore, this is a cost-effective solution to the need for an optical filter in a central office.

Fig. 6 shows the insertion loss spectrum of our crossed optical waveguide coupler. The insertion losses from port A to B at 1625 and 1650 nm were 2.9 and 34.3 dB, respectively. The insertion losses from port A to B at 1310 and 1550 nm were less than 1.9 dB. Moreover, the insertion loss from port C to B at 1650 nm was 1.4 dB. Thus the architecture of this wide-band WDM coupler provides a low insertion loss for the test port and a high dynamic range for the testing system for in-service line monitoring. When the fiber loss of SMF is 0.4 dB/km and the dynamic range of a 1650-nm OTDR with a pulse width of 1 μs is 22.1 dB [19], we can carry out the in-service line monitoring of 50-km-long optical fiber line. In addition, the return loss of each port was more than 40 dB.

We designed the required return loss of the optical filter in the central office using (7) to suppress the ghost signals in the OTDR trace. In the configuration of this crossed optical waveguide coupler that integrates the optical filter and the optical coupler, we consider the required return loss of the optical filter to be that of the TAM, and so $Lcc = 0$ dB. Fig. 7 shows the required return loss of the TAM as a function of the OTDR pulse width corresponding to the Rayleigh backscattering coefficient (Bs). With pulse widths of 20 ns, 100 ns, 500 ns, and 1 μs at the test wavelength of 1650 nm and with the parameters listed

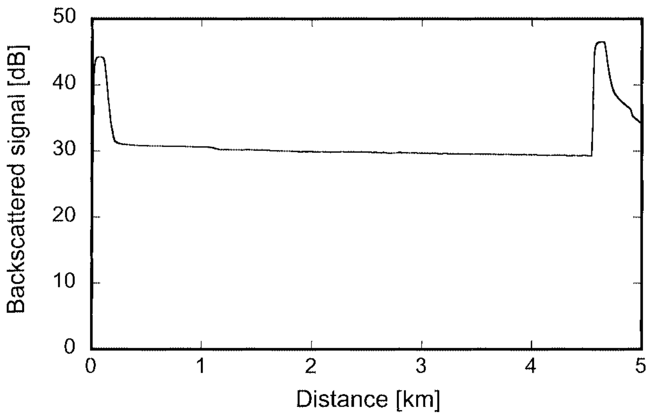


Fig. 8. Experimental OTDR trace using crossed optical waveguide coupler.

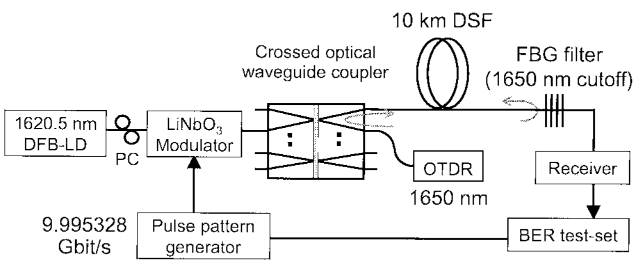


Fig. 9. Experimental setup for measuring bit error rate.

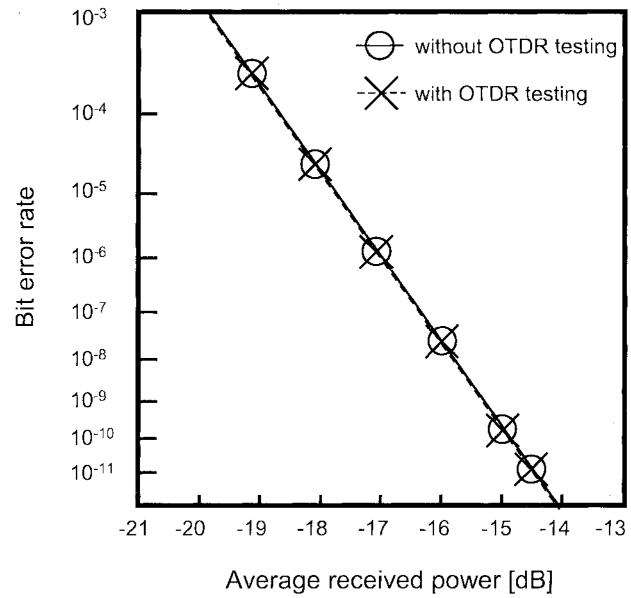


Fig. 10. BER measurement with in-service line monitoring.

below, Bs $= -70$, -63, -56, and -53 dB, respectively. When the return loss of the FBG filter located at the far end of the optical fiber line ref2 is 0.3 dB, the return loss of the TAM has to be more than 39.6 dB to suppress the fluctuation in the OTDR trace to less than 0.2 dB. The measured return loss of port B was 40.6 dB, which met the system requirement for attenuating the multireflection in the OTDR trace.

C. Experimental OTDR Trace Using New L/U-Band Crossed Optical Waveguide Coupler

Fig. 8 shows an experimental OTDR trace that we obtained using the new L/U-band crossed optical waveguide coupler. The OTDR test light wavelength was 1650.1 nm with an FWHM of 0.2 nm. As regards the measurement conditions, the pulse width and the distance range of the OTDR were 1 μs and 5 km, respectively. We measured the same optical fiber line used in Fig. 2 ($Lf = 1.4$ dB, ref2 $= 0.3$ dB). We confirmed that there was no ghost signal caused by multireflection in the OTDR trace when using the crossed optical waveguide coupler.

V. In-Service OTDR Measurement of L-Band Transmission Line

We carried out in-service line monitoring with a 1650-nm OTDR. The experimental setup is shown in Fig. 9. A 1620.5-nm wavelength communication light from a distributed feedback laser diode (DFB-LD) was modulated using a $LiNbO_3$ intensity modulator driven by $2^{31}-1$ nonreturn-to-zero (NRZ) pseudorandom bit stream (PRBS) data at 9.995 328 Gb/s. The communication signal with a power of 1.6 dBm was coupled with an OTDR pulse with a peak power of 17 dBm using our proposed crossed optical waveguide coupler. The OTDR pulse width and pulse period were 1 and 225 μs, respectively (duty: 0.4%). The OTDR pulses were asynchronous as regards the communication signals. The resultant lights were launched into a 10-km dispersion-shifted fiber. The OTDR pulse was rejected at the FBG filter adjacent to the receiver. The insertion losses of the FBG filter at 1620.5 and 1650 nm were 2.2 and 43.4 dB, respectively.

Fig. 10 shows the BER measurement results with and without OTDR testing. To investigate the effect of the OTDR pulse on transmission quality, optical pulses were emitted by the OTDR for the whole duration of our measurement of the averaged BER of the communication signals. In this experiment, there was hardly any deterioration in the BER of the communication signal when the OTDR testing was carried out. To be precise, the communication signals are depleted by Raman-induced crosstalk between the communication light and the 1650-nm test light, and it is important to investigate the transient effect [20]–[23]. However, the transient effect that originated from the OTDR pulse is negligible in access networks even if the OTDR pulse is launched so that it copropagates with the communication signal such as in this experiment [21], [24], because the length of typical optical fiber lines in access networks is less than about 10 km [5] and the effective length of the fiber is short. When we test a fiber of more than 40 km in length, such as in a metro-access network with an OTDR, counterpropagating OTDR testing is an attractive way to suppress the transient effect. This is because the effective length is corresponding to the OTDR pulse width, e.g., 100 m, and so too short to induce the Raman crosstalk. We also confirmed experimentally that there was hardly any degradation in the BER of a C-band transmission at a wavelength of 1552 nm.

Fig. 11 shows an OTDR trace that we obtained when we measured the in-service line of a 10-Gb/s transmission. The OTDR pulse width was 1 μs. There was no ghost signal to indicate multireflection in the OTDR trace, which agreed with the above description, and the OTDR trace was the same as that obtained with offline testing.

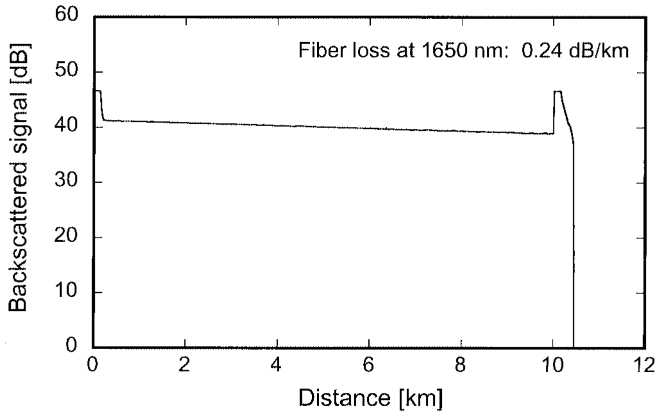


Fig. 11. Experimental OTDR trace when measuring in-service line of 10-Gb/s L-band transmission.

VI. Conclusion

We proposed an extended optical fiber line testing system using ultra-low-cost crossed eight-channel optical waveguide couplers with L/U-band thin dielectric film filters for L-band WDM transmission. We described the design of the return loss required for optical filters located in central offices. We also designed and confirmed the effectiveness of the configuration of a crossed optical waveguide coupler and a thin dielectric film filter with a steep optical spectrum to separate a 1650-nm test light from L-band wavelength light. There was no degradation in the OTDR trace caused by multireflections at optical filters when using our new L/U-band crossed optical waveguide coupler. We also demonstrated the in-service line monitoring of a 10-Gb/s transmission without any degradation in the C- and L-band transmission quality.

Acknowledgment

The authors thank N. Sato, Director of NTT Access Network Service Systems Laboratories, and K. Sato, Project Manager of the Optical Access Network Project, NTT Access Network Service Systems Laboratories, for their continuous encouragement, and Dr. N. Tomita for useful technical discussions.

References

[1] K. Okada, “The vision for HIKARI-soft services,” *NTT Rev.*, vol. 13, no. 4, pp. 4–8, July 2001.

[2] M. Oksanen, O. Hiironen, A. Tervonen, A. Pietilainen, E. Gotsonoga, H. Jarvinen, H. Kaaja, J. Aarnio, A. Grohn, M. Karhiniemi, V. Moltchanov, M. Oikkonen, and M. Tahkokorpi, “Spectral splicing passive optical access network trial,” in *OFC’2002 Tech. Dig.*, Mar. 2002, ThH2, pp. 439–440.

[3] T. Koonen, H. van den Boom, I. T. Monroy, J. Wellen, R. Smets, and G. Khoe, “Optical networking in the access and residential environment – Technologies and challenges,” in *Proc. ECOC’2002*, Sept. 2002, Symposium 2.2.

[4] M. Tachikura, K. Mine, H. Izumita, S. Uruno, and M. Nakamura, “Newly developed optical fiber distribution system and cable management in central office,” in *Proc. 50th IWCS*, Nov. 2001, pp. 98–105.

[5] N. Tomita, H. Takasugi, N. Atobe, I. Nakamura, F. Takaesu, and S. Takashima, “Design and performance of a novel automatic fiber line testing system with OTDR for optical subscriber loops,” *J. Lightwave Technol.*, vol. 12, pp. 717–726, May 1994.

[6] T. Ebihara, N. Nakao, and M. Kuroiwa, “Novel automatic remote fiber line testing system and new fiber termination module for expanding local subscriber loops,” in *Proc. ECOC’96*, vol. 3, Sept. 1996, pp. 39–42.

[7] Y. Enomoto, N. Araki, K. Mine, H. Izumita, and N. Tomita, “Upgraded optical fiber line testing system and its application to optical access networks,” in *Proc. GLOBCOM’98 Access Network Mini Conf.*, 1998, pp. 134–139.

[8] N. Nakao, H. Izumita, T. Inoue, Y. Enomoto, N. Araki, and N. Tomita, “Maintenance method using 1650-nm wavelength band for optical fiber cable networks,” *J. Lightwave Technol.*, vol. 19, pp. 1513–1520, Oct. 2001.

[9] K. Fukuchi, T. Kasamatsu, M. Morie, R. Ohhira, T. Ito, K. Sekiya, D. Ogasahara, and T. Ono, “10.92-Tb/s (273 $\times$ 40-Gb/s) triple-band/ultra-dense WDM optical-repeatered transmission experiment,” in *OFC’2001 Tech. Dig.*, Mar. 2001, PD24.

[10] K. Fukuchi, “Wideband and ultra-dense WDM transmission technologies toward over 10-Tb/s capacity,” in *OFC’2002 Tech. Dig.*, Mar. 2002, ThX5, pp. 558–559.

[11] K. Tsujikawa, Y. Nonoyama, H. Nakamura, T. Ogawa, H. Kawata, and T. Sugie, “Flexible and cost-effective metropolitan and access networks based on coarse-WDM technologies,” in *Proc. Int. Conf. Optical Internet (COIN) 2002*, July 2002, pp. 28–30.

[12] A. Ehrhardt, N. Hanik, A. Gladisch, and F. Rumpf, “Field demonstration of a transparent optical 10 Gbit/s-WDM-network based on normalized transmission sections,” in *OFC’2002 Tech. Dig.*, Mar. 2002, TuH2, pp. 42–43.

[13] S. Ikeda, N. Sakurai, and M. Kitamura, “FM-converted multi-channel video signal transmission system employing low phase noise modulator and parallel demodulator,” in *Proc. Broadband Access Conf. BAC’99*, Oct. 1999, pp. 48–54.

[14] K. Tomita, K. Yoshioka, N. Nakao, and N. Tomita, “Optical fiber distribution in central offices and testing methods for commercial FTTH system,” in *Proc. 47th IWCS*, 1998, pp. 808–814.

[15] “Maintenance wavelength on fibers carrying signals,” ITU-T Standardization Sector, Geneva, Switzerland, ITU-T Rec. L.41.

[16] D. Derickson, *Fiber Optic Test and Measurement*. Englewood Cliffs, NJ: Prentice-Hall, 1997.

[17] Y. Hida, “Ultra-high density AWG’s composed of super-high Δ PLC’s,” in *OFC’2002 Tech. Dig.*, Mar. 2002, ThC6, pp. 399–401.

[18] T. Oguchi, J. Noda, H. Hanafusa, and S. Nishi, “Dielectric multilayered interference filters deposited on polyimide films,” *Electron. Lett.*, vol. 27, no. 9, pp. 706–707, Apr. 1991.

[19] N. Tomita, Y. Enomoto, I. Nakanishi, Y. Koyamada, and N. Atobe, “Advanced optical fiber line testing systems,” in *Proc. NOC’96-3*, June 1996, pp. 30–37.

[20] G. P. Agrawal, *Nonlinear Fiber Optics*, 3rd ed. New York: Academic, 2001.

[21] P. M. Kjeldsen, M. Obro, J. S. Madsen, and S. K. Nielsen, “SRS induced depletion of 1540 nm signal co-propagating with 1630 nm OTDR pulses,” *Electron. Lett.*, vol. 32, no. 20, pp. 1914–1916, Sept. 1996.

[22] A. Bononi and M. Papararo, “Transient gain dynamics in saturated counter-pumped Raman amplifiers,” in *OFC’2002 Tech. Dig.*, Mar. 2002, ThR1, pp. 511–512.

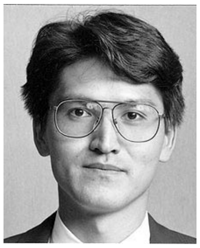
[23] S. Gray, “Transient gain dynamics in wide bandwidth discrete Raman amplifiers,” in *OFC’2002 Tech. Dig.*, Mar. 2002, ThR2, pp. 512–513.

[24] Y. Emori and S. Namiki, “Broadband Raman amplifier for WDM,” *IEICE Trans. Electron.*, vol. E84-C, no. 5, pp. 593–597, May 2001.

Noriyuki Araki was born in Mie, Japan, on March 19, 1971. He received the B.E. and M.E. degrees in electrical and electronic engineering from Sophia University, Tokyo, Japan, in 1993 and 1995, respectively.

He joined NTT Access Network Systems Laboratories, Ibaraki, Japan, in 1995. He is engaged in the research and development of operation and maintenance systems for optical fiber cable networks.

Mr. Araki is a Member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan.



Hisashi Izumita (A'93) was born in Akita, Japan, on February 20, 1964. He received the B.S. and M.S. degrees in physics from Waseda University, Tokyo, Japan, in 1987 and 1989, respectively.

He joined NTT Transmission Systems Laboratories in 1989. He was engaged in research on optical fiber switching techniques and coherent lightwave technology for high performance OTDR and optical fiber distributed sensing. He is presently a Senior Research Engineer with NTT Access Network Service Systems Laboratories and is engaged in the development of systems for optical fiber distribution and management, and fiber maintenance.

Mr. Izumita is a Member of the Optical Society of America (OSA) and the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan.

Nazuki Honda was born in Shizuoka, Japan, on September 8, 1973. She received the B.E. and M.E. degrees in electrical and computer engineering from Yokohama National University, Kanagawa, Japan, in 1996 and 1998, respectively.

She joined NTT Access Network Systems Laboratories, Ibaraki, Japan, in 1998. She is engaged in the research and development of operation and maintenance systems for optical fiber cable networks.

Ms. Honda is a Member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan.

Minoru Nakamura is an Executive Research Engineer of NTT Access Network Service Systems Laboratories. He joined Nippon Telegraph and Telephone Corporation in 1980. Recently, he has been engaged in the development of an optical access network system.