Technique for Measuring Longitudinal Distribution of Raman Gain Characteristics in Optical Fibers

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***Abstract*—This paper proposes a novel technique for measuring the longitudinal distribution of the Raman gain characteristics in concatenated single-mode optical fibers. This technique has an attractive advantage in that the Raman gain efficiency in concatenated optical fibers can be evaluated individually. We describe a measurement principle for obtaining the Raman gain efficiency distribution in optical fibers. We carried out laboratory and field measurements based on this principle, and confirmed that the Raman gain efficiency distribution could be measured easily and accurately.**

***Index Terms*—Distributed amplifiers, optical fiber testing, optical fibers, Raman scattering.**

I. Introduction

THE demand for greater transmission capacity is growing rapidly as a result of the increase in the number of broadband services provided by the Internet. Wavelength-division multiplexing (WDM) technology is a promising way of meeting this demand and is now being actively developed.

Distributed Raman amplification (DRA) has been applied to WDM systems as one approach to extending the WDM channel wavelength range [1]–[3]. DRA gain is available at any wavelength by changing the pump wavelength, and a broad bandwidth can be obtained by combining multiple pump wavelengths [4], [5]. The design of the WDM systems using the DRA requires a sufficient understanding of the Raman gain characteristics in optical fibers that composes optical transmission lines, because the DRA utilizes optical transmission lines as a gain medium.

There have been reports on a technique to estimate the DRA performance in connected optical fibers using optical time-domain reflectometry (OTDR) [6], [7]. In their approaches, the Raman gain efficiency, which depends on the fiber parameters, was used as a constant value in longitudinal direction of the connected optical fibers. In fact, the Raman gain efficiency somewhat varies in optical transmission lines composed of optical fibers, which usually have differences in fiber parameters, such as effective area of fibers. The change in fiber parameters causes a variation in the Raman gain efficiency [8], [9]. Therefore, detailed design of the DRA is necessary to understand the Raman gain efficiency in optical transmission lines.

A technique to measure the Raman gain efficiency has been reported [10]. This technique has been used to investigate the average profile of the Raman gain characteristics in longitudinal direction of one optical fiber. As we described above, however, it is desirable for detailed design of the DRA to measure the Raman gain efficiency in each fiber that composes optical transmission lines.

This paper proposes a technique with which to measure the longitudinal distribution of the Raman gain characteristics in optical fibers. By using this technique, we can evaluate the Raman gain efficiency in concatenated fibers individually. We present the theoretical principle behind this technique. Using this principle as a basis, we performed experiments on various types of fiber and installed an optical transmission line composed of cabled standard single-mode fibers (SMFs).

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II. Measurement Principle

A. Basic Equations

The basic configuration that we used for obtaining the Raman gain characteristics is shown in Fig. 1. Pulse-modulated and continuous-wave (CW) light were used as a pump and a signal light, respectively. These lights were counterpropagated in test fibers. The pulsed pump light was launched into the test fibers at $Z = 0$ and propagated in the $+Z$ direction, while the CW light was launched into the other end of the test fibers ($Z = L$) and propagated in the $-Z$ direction. At $Z = z$, the CW light was amplified by the Raman interaction between the pump and CW lights in the test fibers.

The optical powers of the pump and the CW lights at $Z = z$ in the test fibers are given as follows:

$$P_p(z) = P_p(0) \exp\left[-\int_0^z \alpha_p(Z)dZ\right] \quad (1)$$

$$P_{\rm cw}(z) = P_{\rm cw}(L) \exp\left[-\int_0^{L-z} \alpha_{\rm cw}(Z)dZ\right] \quad (2)$$

where $P_p(0)$ is the pump power at $Z = 0$, and $P_{\rm cw}(L)$ is the CW power at $Z = L$. $\alpha_p(z)$ and $\alpha_{\rm cw}(z)$ are optical loss distributions including the fiber losses and the connection losses at the pump and CW light wavelengths, respectively. The pulse light amplifies the CW light with an interaction length of $vT/2$, where v is the light velocity in the optical fiber and T is the optical pulse width. This is similar to the interaction length for Brillouin amplification in a Brillouin optical time-domain analyzer (BOTDA) [11]. Then, the Raman gain $G(z)$ is as follows:

$$G(z) = \exp\left[\gamma(z)P_p(z)\frac{vT}{2}\right] \quad (3)$$

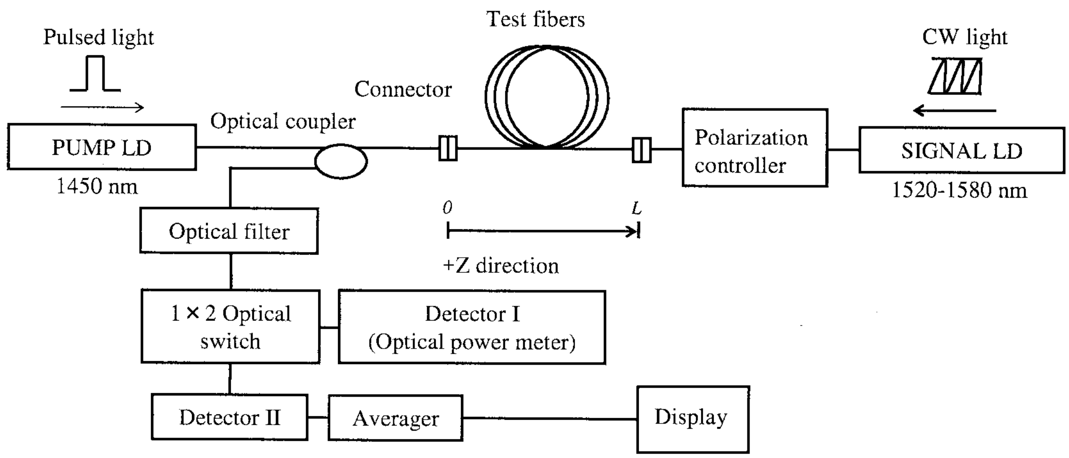


Fig. 1. Basic configuration.

where $\gamma(z)$ is the Raman gain efficiency defined by the Raman gain coefficient per unit of the effective cross-section g/A_{eff}. When we deal with the small gain $G(z)-1 \ll 1$, (3) can be approximated by

$$G(z) \approx 1 + \gamma(z)P_p(z)\frac{vT}{2}. \tag{4}$$

Then, the amplified CW light power $G(z)P_{\rm cw}(z)$ propagates through the test fibers from z to zero with optical attenuation. Therefore, the detected CW power $P_d(z)$ is given by

$$P_d(z) = P_{\rm con} + P_{\rm amp}(z) \tag{5}$$

where

$$P_{\rm con} = P_{\rm cw}(L)\exp\left[-\int_0^L \alpha_{\rm cw}(Z)dZ\right]\cdot C_{\rm cw} \tag{6}$$

$$P_{\rm amp}(z) = P_{\rm con}\gamma(z)P_p(0)\exp\left[-\int_0^z \alpha_p(Z)dZ\right]\frac{vT}{2} \tag{7}$$

and $C_{\rm cw}$ is the total transmission loss of the optical coupler, the optical filter, and the optical switch. The first term in (5) indicates the detected CW power without the Raman amplification (which we call continuous power). The second term indicates the increment in the power of the amplified CW light caused by the Raman amplification (which we call amplified power), which changes with time. These are illustrated in Fig. 2. Consequently, we can derive the Raman gain efficiency distribution $\gamma(z)$ from measured amplified power $P_{\rm amp}(z)$ by measuring following items: a) the continuous power $P_{\rm con}$, b) the pump power launched into the test fibers $P_p(0)$, and c) the pump loss distribution $\alpha_p(z)$. Additionally, we can measure the wavelength dependence of the Raman gain efficiency by changing the CW light wavelength.

B. Measurement of Each Item

Detector I in Fig. 1 is installed through an optical switch and used to measure the continuous power $P_{\rm con}$. The amplified power $P_{\rm amp}(z)$ is measured at the detector and then averaged.

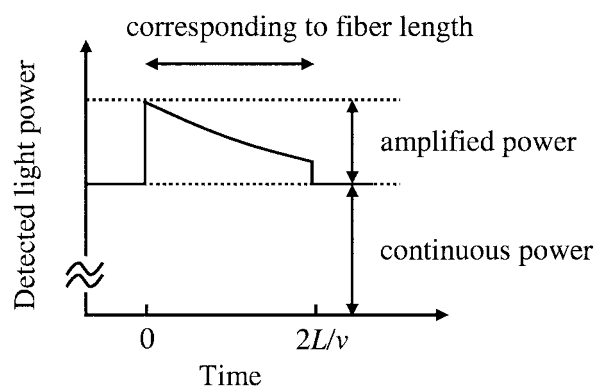


Fig. 2. Schematic illustration of detected CW power.

The pump power launched into the test fibers can be obtained as follows:

$$P_p(0) = P_p(L)\exp\left[\int_0^L \alpha_p(Z)dZ\right] \tag{8}$$

where $P_p(L)$ is the pump power at $Z = L$ and can be easily measured at the fiber end. The pump loss distribution $\alpha_p(z)$ can be obtained by two methods:

1) by using an OTDR that operates at pump wavelength;
2) from bidirectional measurement of amplified power.

For method 1), by using the OTDR, we measure two unidirectional backscattering loss curves, one from each end of test fibers, and obtain the fiber losses and the connection losses of test fibers from average results of both loss curves.

On the other hand, for method 2), the pump loss distribution can be measured by bidirectional measurement of amplified power using the same equipment that we used for the Raman gain efficiency distribution. The amplified power includes two contributions of the pump loss distribution and the Raman gain efficiency distribution in test fibers, as we can see in (7). Therefore, the pump loss distribution can be obtained by distinction between these contributions. Here we provide concrete description for the method 2).

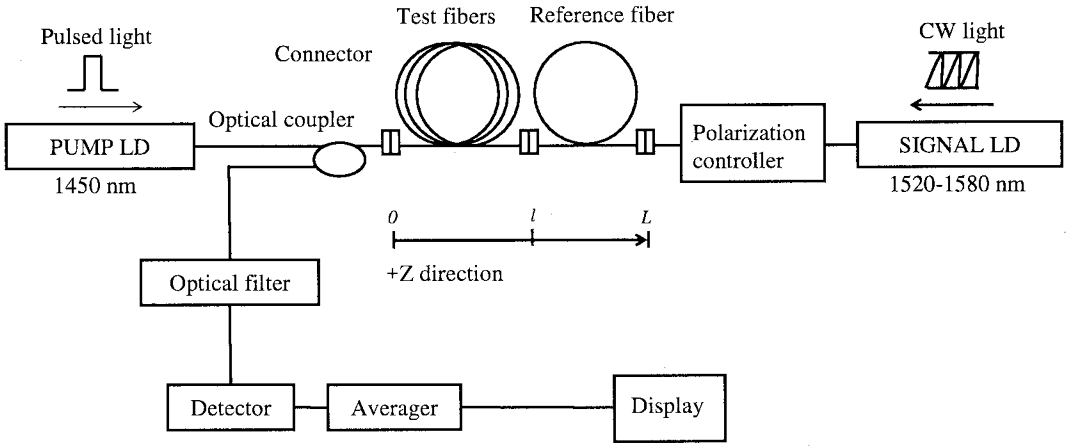


Fig. 3. Configuration employing a reference optical fiber.

When we reverse the test fibers ends $Z = 0$ and L, the directions in which the pulsed pump light and the CW light propagate in the test fibers are reversed. In that case, (7) can be rewritten as follows:

$$P_{\rm amp}^R(z) = P_{\rm con}^R \gamma(L-z) P_p^R(0) \times \exp\left[-\int_0^z \alpha_p(L-Z)dZ\right] \frac{vT}{2} \quad (9)$$

where $P_{\rm con}^R$ and $P_p^R(0)$ are the continuous power and the pump power launched into the test fibers after the fiber ends are reversed, respectively. Then, (7) and (9) yield the following equation:

$$\begin{aligned}\frac{P_{\rm amp}(z)}{P_{\rm amp}^R(L-z)} &= \left(\frac{P_{\rm con}}{P_{\rm con}^R}\right)\left(\frac{P_p(0)}{P_p^R(0)}\right) \\ &\quad \times \exp\left[-2\int_0^z \alpha_p(Z)dZ\right] \exp\left[\int_0^L \alpha_p(Z)dZ\right] \\ &= k \cdot \exp\left[-2\int_0^z \alpha_p(Z)dZ\right] \end{aligned} \quad (10)$$

where k is independent of distance Z. From (11), the relationship between $P_{\rm amp}(z)/P_{\rm amp}^R(L-z)$ and the distance Z on a logarithmic scale shows a distribution of doubled optical loss distribution (in dB) at the pump light wavelength. As a consequence, the pump loss distribution can also be obtained by measuring the amplified powers bidirectionally. This method has a feature in that only the CW signal amplified by Raman amplification is analyzed, and provides us with the pump loss distribution without using the OTDR. Therefore, we do not need to prepare another OTDR even though we measure the Raman gain efficiency distribution at another pump wavelength. But then, the continuous power $P_{\rm con}$ and the pump power launched into the test fibers $P_p(0)$ are required for obtaining the Raman gain efficiency distribution.

C. Measurement Employing a Reference Optical Fiber

As we described above, amplified power also includes the contribution of the Raman gain efficiency distribution in test fibers. Equations (7) and (9) also yield the following equation:

$$\begin{aligned} & P_{\rm amp}(z) P_{\rm amp}^R(L-z) \\ &= P_{\rm con} P_{\rm con}^R P_p(0) P_p^R(0) \left(\gamma(z)\frac{vT}{2}\right)^2 \\ &\quad \times \exp\left[-\int_0^L \alpha_p(Z)dZ\right] \\ &= m \cdot \gamma(z)^2 \end{aligned} \quad (11)$$

where m is independent of the distance Z. Equation (11) indicates that we can obtain the relative change in the Raman gain characteristics in test fibers. Therefore, we can extract only the contribution of the Raman gain characteristics in test fibers from measured amplified power based on (11).

Here we consider that the test fibers are connected to a reference optical fiber with a known Raman gain efficiency distribution, as shown with the configuration in Fig. 3. We named this method the reference method. As described in the above section, we reverse the test fiber end $Z = 0$ and the reference optical fiber end $Z = L$, and change the directions in which the pulsed pump light and the CW light propagate in the test fibers and the reference optical fiber, as shown in Fig. 4. When a value of the Raman gain efficiency at the position in the reference optical fiber $Z = z_{\rm ref}$ is known, the Raman gain efficiency distribution in test fibers normalized by that in the reference optical fiber is expressed using (11) as follows:

$$\left(\frac{\gamma(z_t)}{\gamma(z_{\rm ref})}\right)^2 = \frac{P_{\rm amp}(z_t) P_{\rm amp}^R(L-z_t)}{P_{\rm amp}(z_{\rm ref}) P_{\rm amp}^R(L-z_{\rm ref})} \quad (12)$$

where z_t shows the position in test fibers ($0 < z_t < l$). Therefore, the normalized Raman gain efficiency can be obtained by measuring the amplified power bidirectionally. Then, the Raman gain efficiency distribution in the test fibers can be easily obtained using (12) because the Raman gain efficiency in the reference optical fiber $\gamma(z_{\rm ref})$ is already known. With this approach, we measure only the amplified powers bidirectionally

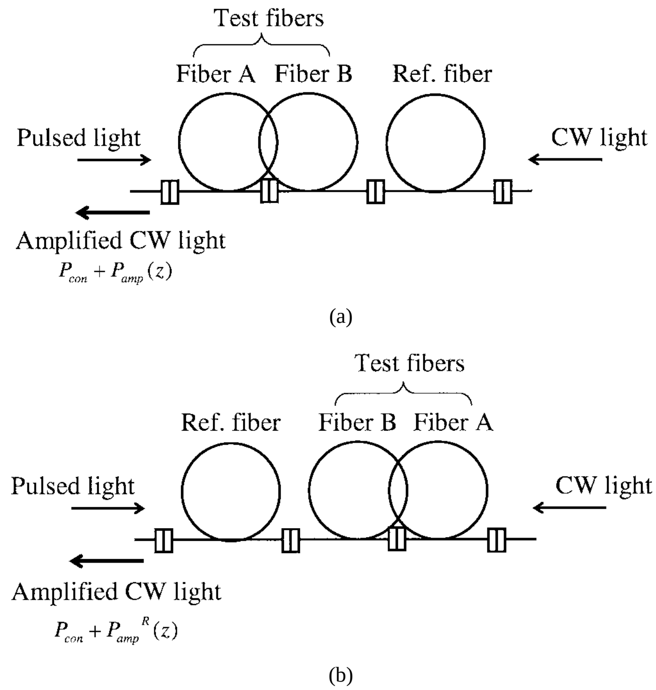


Fig. 4. Schematic illustrations of bidirectional measurement with the reference method.

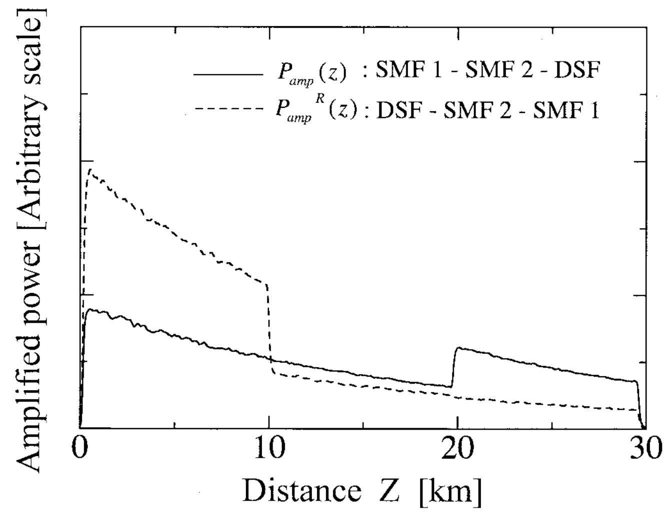


Fig. 5. Example of measured waveforms of the amplified power.

and do not need to measure other items, namely, the pump power launched into the fibers $P_p(0)$, the pump loss distribution $\alpha_p(z)$, and the continuous power $P_{\rm con}$.

III. Experiments and Results

A. Experimental Setup

We used a tunable LD operated in the 1520–1580 nm wavelength range at 5-nm intervals and a modulated LD operated at 1450 nm as the CW light and the pulsed pump source, respectively. The pulse width and the pulse period were 1 and 720 μs, respectively. An optical filter was used to eliminate the Rayleigh scattering caused by the pulsed pump light. To obtain the Raman gain efficiency at the linear state of polarization (SOP) between the CW and the pump light, the SOP was controlled by using a polarization controller composed of a quarter-wave plate ($\lambda/4$) and a half-wave plate ($\lambda/2$) that reduced the fluctuation in the detected Raman amplified power caused by the SOP dependence. This changed the SOP of the CW light by adjusting the angle $\theta 1$ of the axis in the $\lambda/4$ plate and the angle, $\theta 2$, of the axis in the $\lambda/2$ plate. The angles $(\theta 1, \theta 2)$ were $(0^\circ, 0^\circ)$, $(90^\circ, 0^\circ)$, $(90^\circ, 45^\circ)$, and $(0^\circ, 45^\circ)$ for scrambling the SOP [12]. The amplified power at the linear SOP was twice the average values measured for four angles [13].

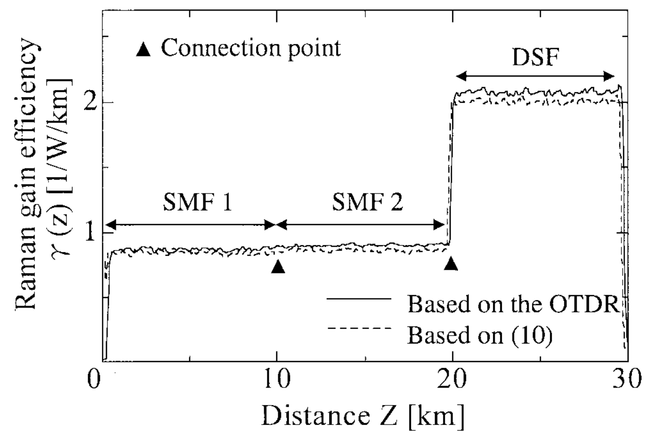
B. Laboratory Measurements of Various Types of Fiber

We examined the Raman gain characteristics of standard SMFs, a dispersion-shifted fiber (DSF). We performed experiments on the concatenated fibers using two methods. The first was the method where we respectively measured the continuous power, amplified power, pump power launched into the test fibers, and pump loss distribution. The pump loss distribution was obtained by the OTDR and the bidirectional measurement of amplified power based on (10) as described in Section II-B. The second was the reference method based on (12) as described in Section II-C.

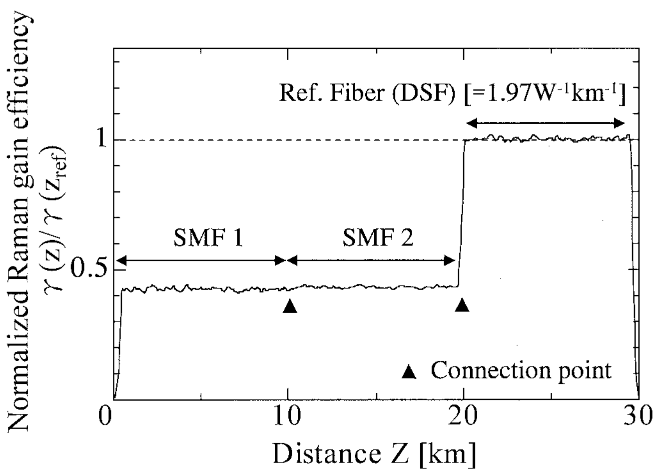
Fig. 5 shows examples of measured waveforms of the amplified power. The solid and dashed lines in Fig. 5 show the respective waveforms before and after the measured fiber ends were reversed. It is seen that the amplified power increased due to the Raman amplification and decreased with distance due to the attenuation of the pump light; and that the distribution of the Raman gain characteristics in fibers was inverted because of the change in the directions in which the pulsed pump and the CW lights propagate. These two waveforms thus can provide us with both the pump loss distribution and the relative change in the Raman gain characteristics in longitudinal direction of fibers.

Fig. 6 shows the Raman gain efficiency distributions obtained with several methods. In Fig. 6(a), the solid line shows the Raman gain efficiency distribution based on the pump loss distribution obtained by the OTDR; the dashed line shows the Raman gain efficiency distribution based on (10). We found that the Raman gain efficiency remained almost constant in the longitudinal direction in each fiber and that the results were very similar. In Fig. 6(b), the Raman gain efficiency distribution, which is based on (12), is normalized by that in the reference optical fiber. The DSF was used as a reference optical fiber with a Raman gain efficiency of 1.97 $\text{W}^{-1}\text{km}^{-1}$. The result obtained by the reference method, which can be calculated from the Raman gain efficiency in the reference optical fiber, 1.97 $\text{W}^{-1}\text{km}^{-1}$, is about 0.85 $\text{W}^{-1}\text{km}^{-1}$ for SMFs. This is in good agreement with the result in Fig. 6(a). We can thus confirm that the Raman gain efficiency distribution can be measured with either method.

The method for the Raman gain characteristics in various types of fiber has been reported by many researchers [10], [15], [16]. Their method is widely used to evaluate the average profile of the Raman gain characteristics in longitudinal direction. Here, we examined four kinds of nonzero DSF and a pure silica core fiber (PSCF) in addition to the SMF and the DSF using the reference method. We also prepared the configuration used in



(a)



(b)

Fig. 6. Obtained Raman gain efficiency distributions with several methods.

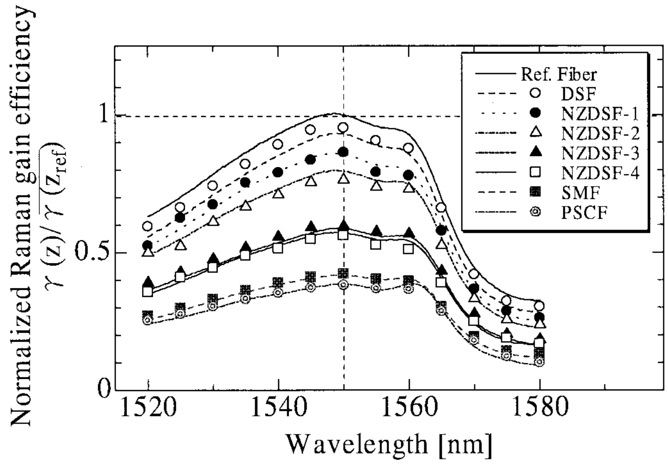


Fig. 7. Wavelength dependence of the Raman gain efficiency for various types of fiber normalized by that for the reference optical fiber at a wavelength of 1550 nm.

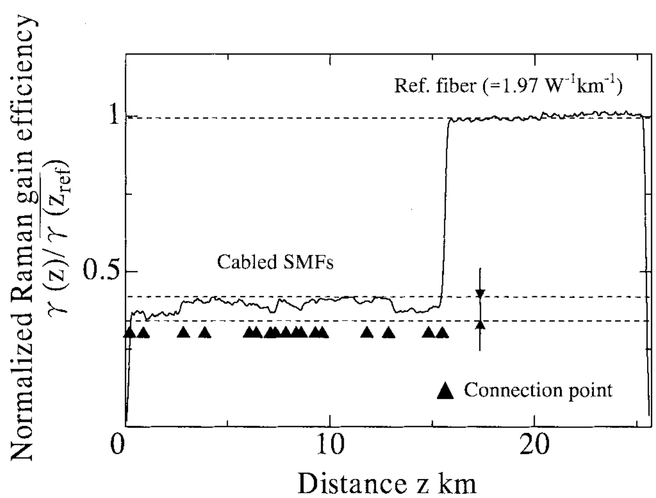


Fig. 8. Normalized Raman gain efficiency distribution of cabled SMFs installed in an optical fiber network at a 1550-nm signal wavelength. The connections contained 16 fusion splices and 1 SC connector.

their method, and measured the Raman gain efficiency to examine the validity of this study.

With their method, a CW laser diode and a broadband CW light-emitting diode are usually used as pump and signal sources, respectively, to measure the spectrum of Raman gain efficiency. Amplified signals and amplified spontaneous emission are detected by an optical spectrum analyzer, and then the Raman gain efficiency in a test fiber is obtained by measuring the on/off gain in signal power, the length and losses of the test fiber, and the pump power launched into the test fiber.

Fig. 7 compares results for the wavelength dependence of the Raman gain efficiency in test fibers normalized by that in the reference optical fiber at a wavelength of 1550 nm. The lines and dots show the results measured by our method and their method, respectively. Results obtained by our method are plotted in the 1520–1580 nm range at 5-nm intervals. We found that the results agreed well, and confirmed that we can measure the wavelength dependence of the Raman gain efficiency in test fibers. Compared with their method, ours has the following attractive advantages: the Raman gain efficiency can be easily obtained without measuring the length, the losses of the test fibers, and the pump power launched into the test fibers if we employ the reference method. Moreover, we can measure the Raman gain efficiency in concatenated fibers individually.

C. Field Measurement of Cabled SMFs Installed in Optical Transmission Line

We also performed a field experiment on SMF cables installed in an optical transmission line using the reference method. The transmission line consisted of underground cables with a total length of about 16 km. The configuration was the same as that shown in Fig. 3. We connected cabled SMFs to the reference optical fiber, and then measured the Raman gain efficiency distribution in the optical transmission line.

Fig. 8 shows the obtained Raman gain efficiency distribution in the cabled SMFs normalized by that in the reference optical fiber. It is seen that the Raman gain efficiency in cabled SMFs varies from about 0.70 to 0.85 $W^{-1}km^{-1}$. This may be due to differences in the fiber parameters, such as an effective cross-section of the optical fibers. This result is close to the result we obtained for SMF in our laboratory measurements. We also confirmed that our technique could be used to measure the Raman gain efficiency distribution in the field.

IV. Conclusion

We proposed a technique for measuring Raman gain characteristics. We confirmed experimentally that this technique enabled us to measure the longitudinal distribution of the Raman gain efficiency for connected optical fibers and the wavelength dependence both easily and accurately. A comparison of this technique with other techniques demonstrated its validity for use with various types of fiber. An experiment on cabled SMFs installed in an optical transmission line revealed the practicality of our technique.

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References

[1] N. Takachio, H. Suzuki, H. Masuda, and M. Koga, "32 × 10 Gb/s distributed raman amplification transmission with 50-GHz channel spacing in the zero-dispersion region over 640 km of 1.55-μm dispersion-shifted fiber," in *Optical Fiber Communication Conf. 1999/Int. Conf. Integrated Optics and Optical Fiber Communication (OFC/IOOC '99)*, 1999, pp. PD9.1–PD9.3.

[2] H. Nakamoto, T. Tanaka, N. Shimojoh, T. Naito, I. Yokota, A. Sugiyama, T. Ueki, and M. Suyama, "1.05 Tbit/s WDM transmission over 8186 km using distributed raman amplifier repeaters," in *Optical Fiber Communication Conf. 2001 (OFC2001)*, 2001, Tuf6–1.

[3] M. Nissov, C. R. Davidson, K. Rottwitt, R. Menges, P. C. Corbett, D. Innis, and N. S. Bergano, "100 Gb/s (10 × 10 Gb/s) WDM transmission over 7200 km using distributed Raman amplification," in *Eur. Conf. Optical Communication 1997 (ECOC1997)*, vol. 5, 1997, PDP, pp. 9–12.

[4] Y. Emori, "Ultrabroadband fiber Raman amplifiers," in *Eur. Conf. Optical Communication 2002 (ECOC2002)*, 2002, 3.02.

[5] S. V. Chernikov, S. A. E. Lewis, and J. R. Taylor, "Broadband Raman amplifiers in the spectral range of 1480–1620 nm," in *Optical Fiber Communication Conf. 1999/Int. Conf. Integrated Optics and Optical Fiber Communication (OFC/IOOC '99)*, 1999, pp. WG6.1–WG6.3.

[6] P. Kim, J. Park, J. Park, and N. Park, "Performance optimization of distributed Raman amplifier using optical pump time domain reflectometry," presented at the Optical Fiber Communication Conf. 2002 (OFC'02), 2002, ThB5.

[7] T. Hoshida, T. Terahara, and H. Onaka, "Performance prediction method for distributed Raman amplification in installed fiber systems based on OTDR data," presented at the Optical Fiber Communication Conf. 2001 (OFC'01), 2001, MI4.

[8] T. Nakashima, S. Seikai, and M. Nakazawa, "Dependence of Raman gain on relative index difference for GeO_2-doped single-mode fibers," *Opt. Lett.*, vol. 10, no. 8, pp. 420–422, 1985.

[9] S. G. Farwell and C. R. S. Fludger, "Experimental determination of variation of the Raman gain efficiency coefficient with fiber mode field diameter and effect on Raman gain," presented at the Eur. Conf. Optical Communication 2002 (ECOC2002), 2002, 5.2.5.

[10] S. Gray, "Raman gain measurement in optical fibers," in *Tech. Dig. Symp. Optical Fiber Measurements 2000*, 2000, NIST Special Pub. 953, pp. 151–154.

[11] T. Horiguchi and M. Tateda, "BOTDA-nondestructive measurement of single-mode optical fiber attenuation characteristics using brillouin interaction: Theory," *J. Lightwave Technol.*, vol. 7, pp. 1170–1176, Aug. 1989.

[12] D. Hamoir, N. Torabi, A. Bergonzo, S. Borne, and D. Bayart, "Raman spectra of line fibers measured over 30 THz," in *Tech. Dig. Symp. Optical Fiber Measurements 2000*, 2000, NIST Special Pub. 953, pp. 147–149.

[13] H. Izumita, S. Furukawa, Y. Koyamada, and I. Sankawa, "Fading noise reduction in coherent OTDR," *IEEE Photon. Technol. Lett.*, vol. 4, no. 2, pp. 201–203, 1992.

[14] R. H. Stolen, "Issues in Raman gain measurements," in *Symp. Optical Fiber Measurement 2000 (SOFM2000)*, 2000, pp. 139–142.

[15] Y. Qian, J. H. Povlsen, S. N. Knudsen, and L. G. Nielsen, "On rayleigh backscattering and nonlinear effects evaluations and Raman amplification characterizations of single-mode fibers," in *Optical Amplifiers and Their Applications (OAA 2000)*, 2000, OMD18–1, pp. 91–93.

[16] C. Fludger, A. Maroney, and N. Jolley, "An analysis of the improvements in OSNR from distributed Raman amplifiers using modern transmission fibers," in *Optical Fiber Communication Conf. 2000*, vol. 4, 2000, pp. 100–102.

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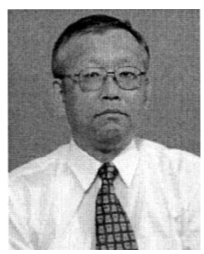

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