Application of Ultra-Low Bending Loss Fiber "PureAccess-R5" to Optical Wiring in FTTx Access Networks

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In 2002, Sumitomo Electric launched its leading edge low bending loss fiber "PureAccess" that has an allowable bending radius of 15 mm. By virtue of its improved handling, the company has contributed to the construction of FTTx networks through its info-communications technology and products including cables, termination boxes and connectors. As the FTTx networks expand throughout the world, there is an ever increasing demand for fiber that facilitates overall space savings and decreases deployment time and costs. To meet the demand, we have developed a new ultra-low bending loss fiber "PureAccess-R5," which shows negligible bending loss even at a bend as small as 5 mm radius. The PureAccess-R5 is fully compliant with ITU-T G.657.B3 Recommendation, the new standard established in 2009 for minimum bending radius of 5 mm. Furthermore, the PureAccess-R5 is designed to have almost the same MFD (mode field diameter) as the conventional PureAccess, and therefore, can be connected with low coupling loss to existing access networks. This paper shows the transmission characteristics of the PureAccess-R5 including its low bending loss and low loss connectivity to existing fibers. We also describe the application of this fiber to PureFlex-slim indoor cable, which has high durability and flexibility. This newly fabricated cable realizes more reliable and flexible indoor wiring. The cable also shows excellent stability in attenuation and transmission characteristics under severe bending tests simulating actual installation and handling. Thus it is confirmed that the PureFlex-slim cable with PureAccess-R5 fiber has ideal characteristics for FTTx wiring.

Keywords: single mode fiber, bend insensitive fiber, FTTH, FTTx

1. Introduction

Since 2002, Sumitomo Electric has been proposing bend-improved fiber (PureAccess) in order to realize easy deployment of FTTx. PureAccess reduces the allowable bending radius to 15 mm, which is half of standard single mode fiber. We have also contributed to successful construction in the FTTx system by introducing related optical component products such as optical cables, MDU (multi-dwelling unit) cabinets, and so on. Recently, there is a worldwide growing demand of FTTx deployment, which requires further bendable fiber to reduce the installation time, cost, and handling troubles in the home, central office, and data center. To cope with the demands, we have succeeded in manufacturing PureAccess-R5, which can be bent at 5 mm radii with no significant loss increment.

PureAccess-R5 is a newly introduced bend-insensitive fiber complying with ITU-T G.657.B3 Recommendation, which prescribes the bend loss at bending radius of 5 mm. Although, the range of mode field diameter (MFD) in G.657.B3 is ranging from 6.3 μm to 9.5 μm, MFD of PureAccess-R5 is designed to be identical with that of PureAcccess. Hence, it is expected the small coupling loss to the existing access network.

In this paper, optical characteristics of the PureAccess-R5, including bending performance and coupling loss, are reviewed. Then we have applied this fiber to indoor wiring cable PureFlex-slim[(2)], which is durable and flexible compared with our previous indoor wiring cable PureFlex. By applying PureAccess-R5 to PureFlex-slim, we confirmed that the manufactured cable is durable and virtually free from bending radii restriction, hence higher flexibility is realized in installation of the cable. Finally, we have conducted various installation demonstrations and transmission experiments to verify the performance.

2. Optical Characteristics of PureAccess-R5

2-1 ITU-T G.657 Recommendation and optical characteristics of PureAccess-R5

Table 1 shows the classification in minimum bending radius of ITU-T G.657 Recommendation. PureAccess-R5 is classified to G.657.B3, which has a smallest bending radius. **Table 2** summarizes the specification of PureAccess-R5 in comparison with standard single mode fiber, PureBand, and bend improved fiber, PureAccess. By employing the

Table 1. Outline of ITU-T G.657 Recommendation

ITU-T	G.657			
Sub category	A1	A2	B2	B3
MFD	8.6-9.5μm		6.3-9.5μm	
Min, bend radius	R=10mm	R=7.5mm	R=7.5mm	R=5mm
	PureAccess	–	–	**PureAccess-R5**

trench-type index profile, PureAccess-R5 is designed to suppress the bending loss to meet the G.657.B3 classification, while keeping equivalent MFD to that of PureAccess.

Table 2. Specifications of PureAcccess-R5, PureAcccess and PureBand

Product name		PureBand	PureAccess	PureAccess-R5
ITU-T category		G.652.D (Standard SMF)	G.657.A1	G.657.B3
Bending loss	Bending radius	R=30mm	R=10mm	R=5mm
	@1550nm	–	<0.25dB/10turn	<1.0dB/10turn
	@1625nm	<0.1dB/100turn	<1.0dB/10turn	<2.5dB/10turn
Geometry	MFD	9.2μm	8.6μm	8.6μm
	Core-Clad concentricity	<0.8μm	<0.4μm	<0.5μm
	Cladding non-circularity	<1.0%	<1.0%	<1.0%
Optical characteristics	Attenuation (α) 1310nm-1625nm 1383nm 1550nm	<0.4dB/km <α at 1310nm <0.3dB/km	<0.4dB/km <α at 1310nm <0.3dB/km	<0.4dB/km <α at 1310nm <0.3dB/km
	Cable cutoff wavelength	<1260nm	<1260nm	<1260nm

2-2 Bending performance

Figure 1 shows the bending loss spectrum of PureAccess-R5 in comparison with standard SMF and PureAccess while applying bending by a 5 mm radius mandrel. These three fibers increase in their bending loss to the longer wavelength region, but PureAccess-R5 shows very small bending loss of less than 0.25 dB/turn at 1625 nm. This feature is advantageous for PON (passive optical network), where wide wavelength band ranging from 1260 nm to 1625 nm is used, and for network where loss budget margin is small.

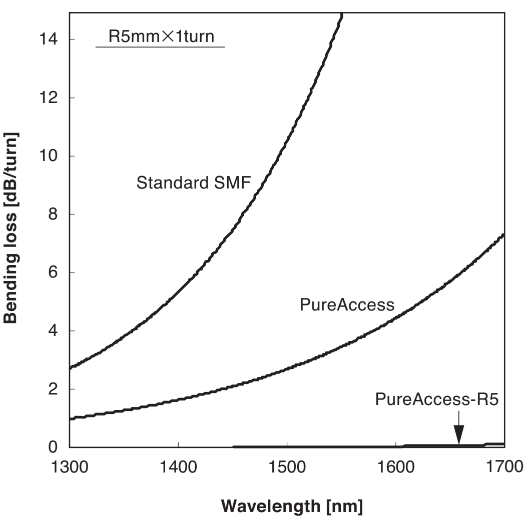

Fig. 1. Comparison of wavelength dependence of bending loss

2-3 Coupling loss

Figure 2 shows histogram of fusion splice loss between PureAccess-R5 to PureAccess **(a)** and to standard SMF **(b)** for 50 times. As for the splice to PureAccess, typical splice losses were 0.03 dB at wavelength of 1310 nm and 1550 nm, respectively. In the case of standard SMF, typical splice losses were 0.04 dB at 1310 nm, and 0.06 dB at 1550 nm, respectively. **Table 3** summarizes the splice loss and connector coupling loss characteristics of PureAccess-R5 to various types of fibers. As can be seen in the table, PureAccess-R5 can be coupled with most of the existing fibers with sufficiently small loss.

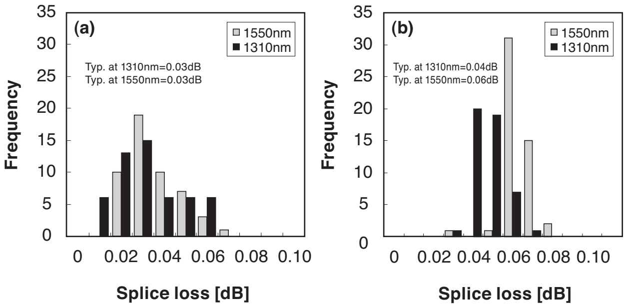

Fig. 2. Fusion splice loss between (a) PureAccess-R5 to PureAccess, (b) PureAccess-R5 to standard SMF

Table 3. Splice loss and connecter coupling loss between PureAccess-R5 and various fiber (typical value)

	vs PureAccess-R5		vs PureAccess		vs Standard SMF	
Wavelength	1310nm	1550nm	1310nm	1550nm	1310nm	1550nm
Splice loss	<0.1dB	<0.1dB	<0.1dB	<0.1dB	<0.2dB	<0.2dB
SC connector Coupling loss	<0.1dB	<0.1dB	<0.1dB	<0.1dB	<0.2dB	<0.2dB

3. Application Example of PureAccess-R5 to FTTx Wiring

Figure 3 shows the example of FTTx system configuration using PureAccess and PureAccess -R5. Thanks to the controlled bending condition from a central office to each drop point, extreme bend is not applied. Hence, PureAccess with allowable bending radius of 15 mm can be a cost-efficient choice. On the other hand, PureAccess-R5 with allowable bending radius of 5 mm, is preferably applied for harsh deployment condition, such as inside the central office where there may be a case to be applied a tight bend during wiring operation among the crowded in-service fiber and accompanying instantaneous interruption of the signal traffic, indoor wiring where fiber cable could be stapled onto the wall or handled directly by subscribers. By combined use of these two types of bend insensitive fiber series, economical and efficient deployment can be realized. In this chapter, we show the result of indoor wiring demonstration by using PureAccess-R5.

Optical fiber	— PureAccess	**— PureAccess-R5**
Length	~ several 10 kms	**~ several 10 ms**
Deployment condition Telecom controlled?	Yes	**No**

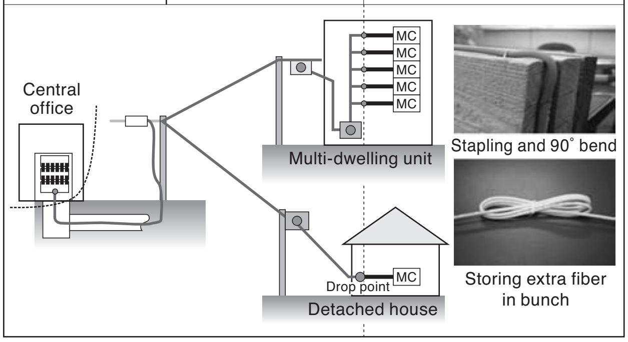

Fig. 3. FTTx deployment example using PureAccess-R5 and PureAccess

3-1 High durability and flexibility cable

In order to evaluate applicability on actual access systems, we fabricate indoor wiring cable PureFlex-slim using PureAccess-R5. PureFlex-slim have both high “mechanical durability” and “flexibility,” which are important features for cable deployment. **Figure 4** shows a cross section of PureFlex-slim. A strength member yarn, which is specially enhanced in resistance to tension, is arranged around the fiber, and halogen-free flame-retardant polyethylene with high flexibility is used as outer coating. By selecting proper materials, the outer diameter of PureFlex-slim is reduced to 3 mm from that of the previous indoor cable (PureFlex) of 5 mm.

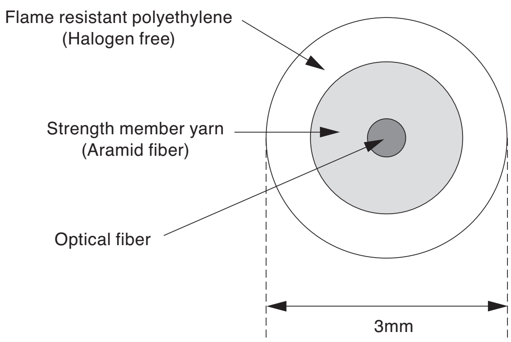

Fig. 4. Cross section of PureFlex-slim cable

3-2 Transmission loss by deployment with stapling

As usually adopted in electrical wiring, deploying the fiber cable on the wall inside house by stapling is often applied for FTTx wiring[4]. By stapling, a fiber inside the cable is bent in a small radius. For such applications, PureAccess-R5 is considered optimal. Hence, we measured the transmission loss increments by stapling using PureFlex-slim cable with PureAccess-R5. As a reference, we also prepared PureFlex-slim with PureAccess and the fiber complying G.657.A2.

The picture of a staple used in this study and the appearance of the stapled cable are shown in **Photo 1 and 2**, respectively. As shown in **Photo 2**, used stapler drove staples to wooden board until the diameter of the cable becomes approximately by 1/2. **Figure 5** shows changes in received power by stapling. In the case of PureAccess, received power decreased by about 3dB after stapled for 20 times. As for the case of fiber complying with G.657.A2, though the cable shows smaller change in received power as compared with PureAccess, the decrease in received power was observed. In contrast, PureAccess-R5, shows almost no changes in received power even after 100 times stapling. Therefore, PureFlex-slim with PureAccess-R5 can suppress the degradation of transmission quality by stapling as compared with other fibers. It should be noted that the stapling applies large bending stress on to fiber, and may cause breakage. So, care should be taken on the shape of staples and choice of staplers.

Photo 1. Flat staple used in the test

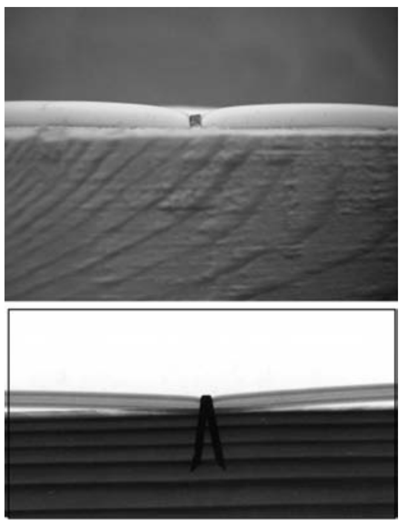

Photo 2. Appearance of stapled (top)PureFlex-slim and its X-ray photograph (bottom).

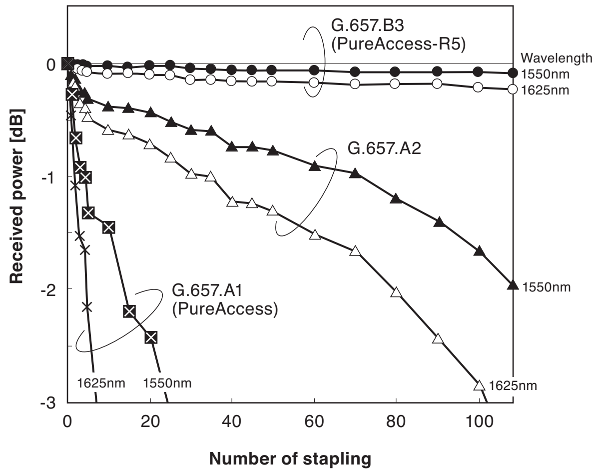

Fig. 5. Changes in received power by stapling

3-3 MPI characteristics

Generally, fiber with low bending loss tends to confine not only fundamental mode but also higher order modes. In such case, multi-path interference (MPI)[(5)], which is a power fluctuation caused by the interference between a fundamental mode and a higher order mode, may occur. In order to ensure the transmission quality, it is reported that the MPI should be suppressed below -30 dB[(5)]. Therefore, MPI characteristic of PureAccess-R5 was measured using a setup shown in **Fig. 6**. We also measured MPI of stapled PureFlex-slim with PureAccess-R5, because higher order mode may be induced by bending the fiber. **Figure 7** shows measured results. MPI of PureAccess-R5 were always below -45 dB at the wavelength of 1310 nm and 1550 nm and no significant change were observed.

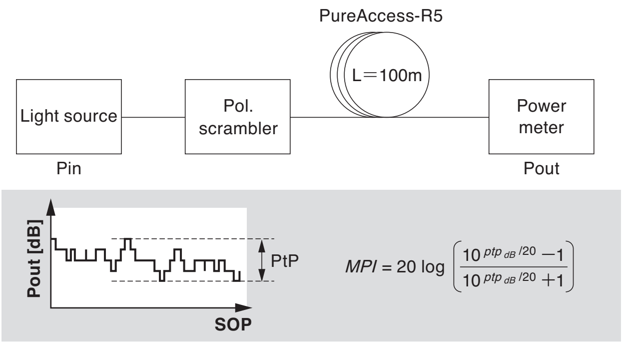

Fig. 6. Measurement setup of MPI

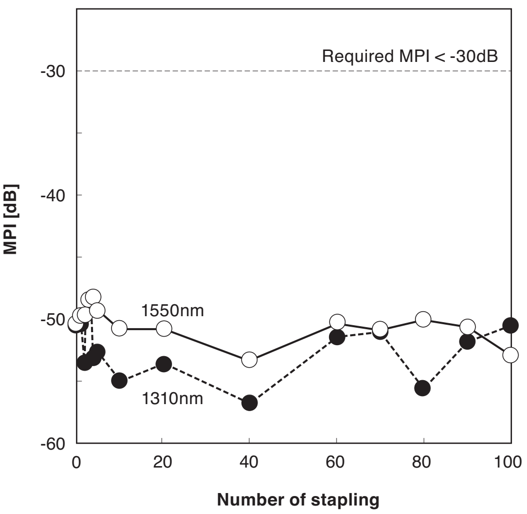

Fig. 7. Change in measured MPI by stapling

3-4 Transmission loss changes under harsh mechanical impact and deformation

Exposed cable in house wiring could be suffered by various mechanical deformation and impact such as "stamped by a dweller or household furniture," "struck by pointed stuff or bitten by a pet animal." and "bent at a right angle (90˚) with load," In order to verify transmission stability in such a harsh situation, we applied a special tests depicted from **Fig. 8** to **Fig. 10** in addition to the test conditions described in IEC60794-1-2. As summarized in **Table 4** and

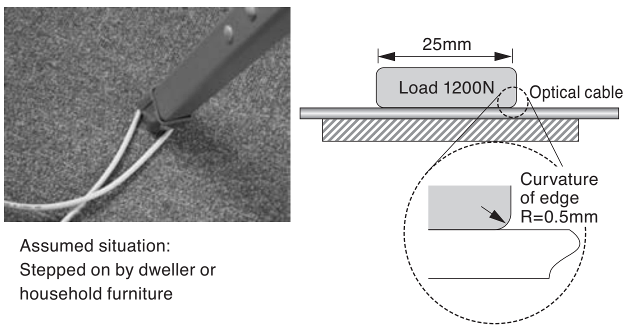

Fig. 8. Apparatus of crush test and assumed situation

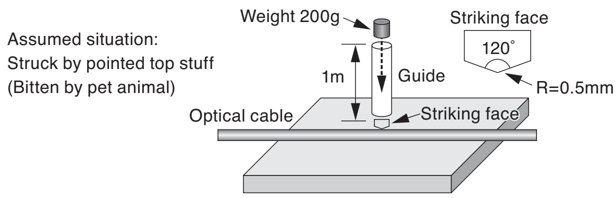

Fig. 9. Apparatus of impact test and assumed situation

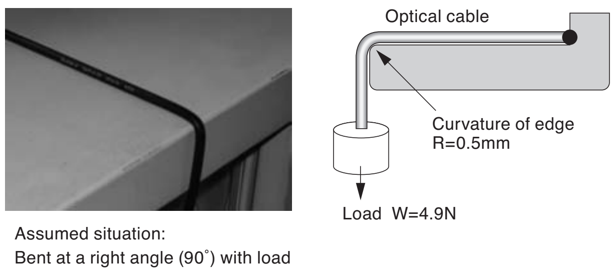

Fig. 10. Apparatus of L-bend test and assumed situation

Table 4. Transmission loss increase by applying various mechanical deformation, shock, and temperature cycling (IEC60794-1-2)

Item	Test condition	Result		
		G.657.B3 (PureAccess-R5) PureFlex-slim	G.657.A1 (PureAccess) PureFlex-slim	SMF cord
Repeated bending	R15mm × ± 180°× 5cycle	No change	No change	No change
	R5mm × ± 180°× 5cycle	No change	< 0.5dB	> 5.0dB
Repeated bending under load	R12.5mm, Load = 19.6N × 1000cycle	No change	No change	< 0.5dB
Repeated winding	R15mm × 6turn × 10cycle	No change	No change	< 0.5dB
	R5mm × 6turn × 10cycle	No change	< 1.0dB	> 10dB
Crush test	1200N/25mm plate (Edge curvature R5mm)	No change	No change	< 0.1dB
Shock resistance	2.94N, ø25mm × 1m	No change	No change	No change
Temperature cycling	-10~+40°C × 3cycle	< 0.05dB/km	< 0.05dB/km	< 0.1dB/km

Table 5. Transmission loss increase under harsh mechanical deformation

Item	Test condition	Result		
		G.657.B3 (PureAccess-R5) PureFlex-slim	G.657.A1 (PureAccess) PureFlex-slim	SMF cord
Crush test with sharp edge	1200N/25mm plate (Edge curvature R0.5mm)	No change	< 0.2dB	> 1.0dB
Impact test	1.96N, ø25mm × 1m Angle of striking face 120° R0.5mm	No change	No change	Cord disconnection
L-bend test	R0.5mm, 4.9N	No change	< 0.1dB	> 5.0dB

Table 5, PureFlex-slim with PureAccess-R5 shows no loss increase in any test conditions, where the cable or cord using other fiber shows substantial loss increase.

By these tests described in chapter3, we confirmed the PureFlex-slim with PureAccess-R5 has sufficient stability and reliability in transmission characteristics even for wiring at an exposed portion in a house. This product is expected to be the best for the uncontrolled bending conditions.

4. Transmission performance

4-1 10-Gbps transmission test and stability

As for next-generation access systems, 10G-PON and 10GE-PON have been standardized, and development aiming at commercialization is being undertaken. Therefore, the fiber needs to support stable transmission even in such a high-speed access system.

However, in actual deployment, such as inside central offices or datacenters, transmission of in-service fibers (cables) can be interrupted due to the vibrations generated by wiring operation for installation of additional ports or system maintenance in a heavily crowded space.

Moreover, in house wiring, various vibrations could be applied on deployed optical cable from electrical equipment or daily activities. In order to confirm that PureAccess-R5 surely tolerate such conditions, we applied strong vibrations (10 cm in amplitude and 10 Hz in frequency) to 100-meter PureAccess-R5 using setup shown in **Fig. 11**, and measured the bit error rate under 10 Gbps transmission at wavelength of 1310 nm and 1550 nm. As shown in **Fig. 12**, any error floor was observed for both with and without vibration for the wavelength of 1310 nm and 1550 nm. So the PureAccess-R5 can certainly support high speed transmission and is able to be handled easy, so the efficient and reliable wiring operation will be realized.

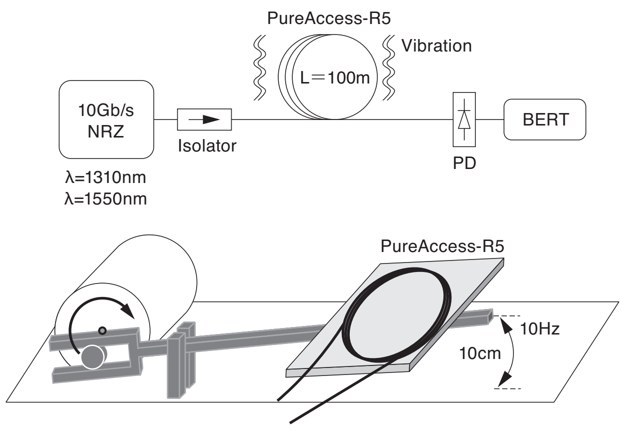

Fig. 11. Bit error rate measurement setup under fiber vibration

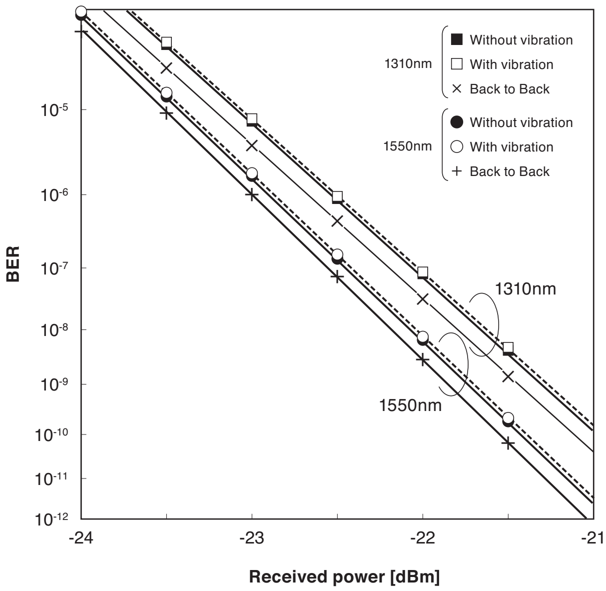

Fig. 12. Bit error rate under 10 Gbps transmission with or without applying vibration

5. Conclusions

PureAccess-R5 complying with ITU-T G.657.B3, is confirmed to have both low bending loss characteristics and low splice loss with existing fibers. The optical cable using PureAccess-R5 shows excellent stability in transmission characteristics in assumed severe bending situations, such as in house, central office, and so on. Furthermore, PureAccess-R5 can be applied to next-generation high-speed access systems of 10G-PON and 10GE-PON. Therefore, PureAccess-R5 is ready to use in both conventional and future access systems and expected to contribute to further FTTx network developments.

* PureBand, PureAccess and PureFlex are trademarks or registered trademarks of Sumitomo Electric Industries, Ltd.

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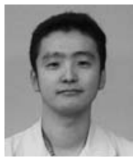

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