10G-EPON Dense Wavelength Division Multiplexing Repeater Expands Transmission Distance up to 60 km

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We provide advanced broadband technologies and passive optical network (PON) equipment to the market. Recently, we have developed a repeater for 10 Gigabit-Ethernet PON (10G-EPON) systems. Installed between an optical line terminal (OLT) and optical network units (ONUs), the repeater significantly expands the data transmission distance from the conventional 20 km to 60 km. Wavelength division multiplexing (WDM) technology enables its connection to the OLT using an optical fiber and 8 channel support. This paper describes the performance of the repeater and the key technology in relaying upstream burst signals.

Keywords: 10G-EPON, repeater, wavelength division multiplexing (WDM)

1. Introduction

As the technology for providing optical broadband access and spreading Fiber-to-the-Home (FTTH) networks, a passive optical network (PON), which enables efficient use of optical fibers by allowing several subscribers to share a single fiber, has been introduced. We have commercialized communication systems based on the Gigabit-Ethernet (GE-PON)*[1] and sold them to domestic and overseas communication carriers. In 2014, we started providing a 10G-EPON*[1] system that has a transmission capacity 10 times larger than GE-PON.(1)

From the viewpoint of cost, there are strong demands for accommodating more subscribers in wider areas by extending the transmission distance and increasing the number of branches, and by using optical fibers more efficiently through the introduction of wavelength division multiplexing (WDM).*[2] However, extending and branching optical fibers increases transmission loss, which needs to be compensated.

As a solution for extending communication distance, accommodating more subscribers, and realizing WDM transmission, we had developed a GE-PON repeater.(2) This configuration actualizes WDM transmission between the OLT and the repeater, which improves the efficiency of data transmission using optical fibers. This paper describes the features of a newly developed 10G-EPON repeater dedicated to 10G-EPON systems and its characteristics.

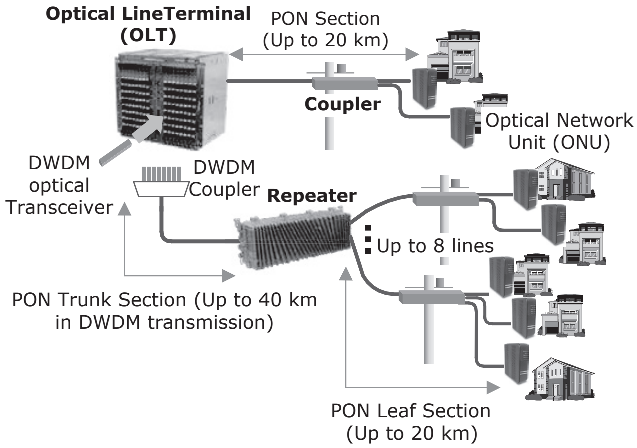


Fig. 1. Application of a 10G-EPON Repeater

2. Outline of the Repeater

2-1 Features

Figure 1 shows an application of the new 10G-EPON repeater. This repeater is installed in the section between the optical line terminal (OLT) and optical network unit (ONU) (PON section). It receives upstream/downstream optical signals,*[3] converts them to electrical signals, reprocesses the signals, converts them back to optical signals, and sends them out. It compensates for transmission loss by amplifying weakened optical signals. For the part between the repeater and the ONU (PON leaf section), a maximum transmission distance of 20 km, which is equivalent to the distance of a normal PON section, is achieved in the case of 32 branches. Therefore, the total transmission distance can be extended by extending the distance between the OLT and the repeater (PON trunk section). Using dense WDM (DWDM) transmission in the PON trunk section, a single repeater provides 8-channel wavelength multiplex transmission. For the wavelength multiplexing on the OLT, a DWDM optical transceiver has been developed. Since it is pin-compatible with the conventional optical transceiver on the OLT, it can replace the conventional transceiver, and realize wavelength multiplex transmission with the repeater.

In addition, this repeater provides 10G synchronous (10 Gbit/s downstream and 10 Gbit/s upstream) and 10G asynchronous (10 Gbit/s downstream and 1 Gbit/s upstream) communication. For the upstream, the repeater receives optical burst signals*[4] with different transmission rates and amplitudes, converts them to an optical pseudo continuous signal with an identical amplitude, and sends them to the OLT. Leveling the optical amplitudes stabilizes emission wavelengths, facilitating wavelength multiplexing in the PON trunk section.

Table 1 indicates the main specifications of the repeater. The PON trunk interface (I/F) on the OLT has a DWDM optical transceiver that supports transmission over 40 km. The PON leaf I/F on the ONU has an OLT optical transceiver, which realizes transmission characteristics similar to those of a normal PON section. With this configuration, the maximum transmission distance between the OLT and ONU is 60 km, which is the total of 40 km for the PON trunk section and 20 km for the PON leaf section.

Table 1. Main Specifications of the Repeater

Item	Specifications
Cabinet Dimensions	708 (W) x 217 (D) x 253 (H) mm
Number of Repeater Channels	8 channels
Downstream Transmission Rate	10 Gbit/s (Physical layer: 10.3125 Gbit/s)
Upstream Transmission Rate	10 Gbit/s (Physical layer: 10.3125 Gbit/s) 1 Gbit/s (Physical layer: 1.25 Gbit/s)
Repeater Processing Unit PON Trunk I/F (OLT Side)	XFP DWDM optical transceiver - Downstream reception: 10.3125 Gbit/s - Upstream transmission: 10.3125 Gbit/s and 1.25 Gbit/s - Wavelength: DWDM100 GHz grid ch20 to ch35 (1561.42 to 1549.32 nm)
Repeater Processing Unit PON Leaf I/F (ONU Side)	XFP OLT optical transceiver (conforming to IEEE802.3 10/1GBASE-PR30) - Downstream transmission: 10.3125 Gbit/s - Upstream reception: 10.3125 Gbit/s and 1.25 Gbit/s
Power Consumption	86 W (typical)

2-2 Internal structure

Figure 2 illustrates the configuration of the repeater and Photo 1 shows its internal structure. A cabinet for outdoor installation houses a repeater unit (8-channel), DWDM multiplexing/demultiplexing coupler, and power unit.

The configuration of the relay processing unit (one channel) is indicated in Fig. 3. For downstream 10G relay processing, a DWDM optical transceiver receives the 10G optical continuous signal from the OLT (optical-to-electric conversion), a clock and data recovery (CDR) circuit*[5] for the continuous signal regenerates timing, and a transceiver for the OLT transmits an optical signal to the ONU (electric-to-optical conversion). The CDR circuit extracts 10G clock from the 10G signal and passes it to the upstream 10G/1G relay processing section. The repeater synchronizes itself with the OLT by operating the 10G/1G relay process on the clock signal extracted from the downstream signal.

In upstream 10G/1G relay processing, the OLT optical transceiver receives optical burst signals consisting of the 10G signal (10.3125 Gbit/s) from the 10G symmetric ONUs and the 1G signal (1.25 Gbit/s) from the 10G asymmetric ONUs (and performs optical-to-electric conversion). The transceiver determines whether a burst signal exists by checking the strength of the optical burst signal. When a burst signal is detected, both 10G and 1G CDR circuits try

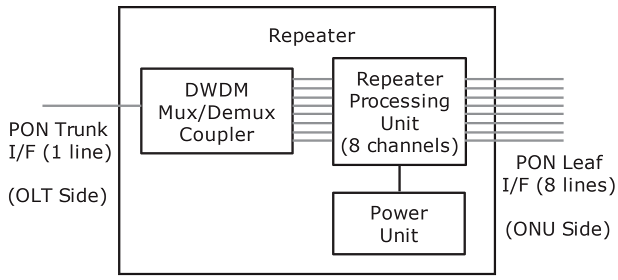
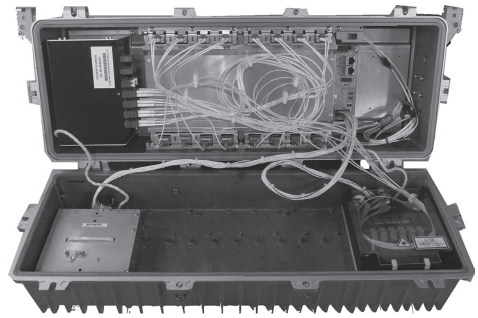


Fig. 2. Configuration of the Repeater



Top Middle: Repeater processing unit (8 channels)
Top Left: DWDM multiplex/demultiplex coupler
Bottom Left: Power unit

Photo 1. Internal Structure of the Repeater

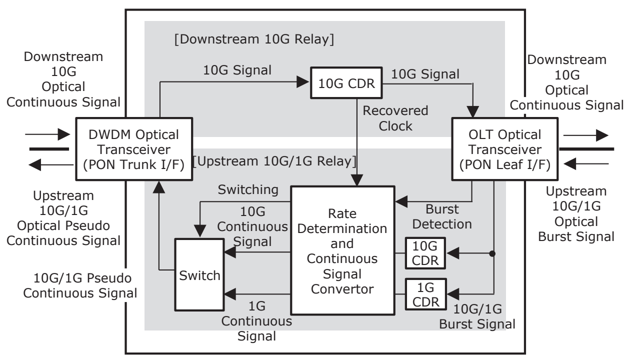


Fig. 3. Configuration of the Repeater Processing Unit

synchronization simultaneously and the rate determination section judges whether a 10G or 1G burst signal is being received. The OLT allocates communication resources to each ONU. It knows whether the received burst signal is a 10G signal or a 1G signal. However, the repeater has no knowledge of the transmission rate of the burst signal. It has to receive the signal before making judgment.

After rate determination, a dummy signal is inserted in each non-signal interval in the outputs from the 10G and 1G CDR circuits to generate a 10G continuous signal and a 1G continuous signal. The two continuous signals are combined with a switch into a 10G/1G pseudo continuous signal. The DWDM optical transceiver transmits the signal to the OLT (electric-to-optical conversion).

Figure 4 indicates the process of converting a 10G/1G optical burst signal to a 10G/1G optical pseudo continuous signal. The optical pseudo continuous signal is a mixture of the 10G signal and the 1G signal. It is an optical continuous signal with a constant output level. To distinguish it from an optical continuous signal with a single transmission rate, it is called an "optical pseudo continuous signal" here. Unlike an optical burst signal, the light emitting device constantly emits light so that its temperature and light wavelength are stabilized, which facilitates wavelength multiplexing by the DWDM optical transceiver.

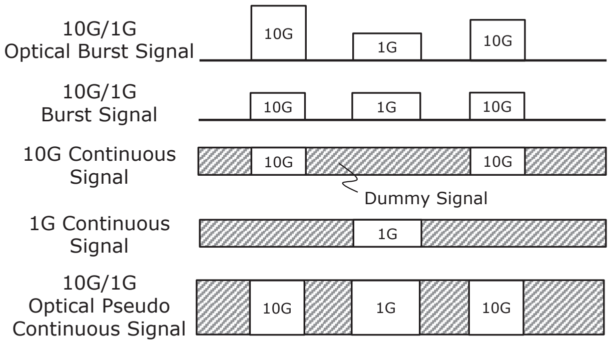


Fig. 4. Generation of 10G/1G Optical Pseudo Continuous signal

In a 10G-EPON, the receiving side corrects transmission errors occurring in the PON section using error correction technology. This repeater does not perform error correction. It repeats transmission errors generated in the downstream PON trunk section as they are, which, in conjunction with the transmission errors generated in the PON leaf section, will be corrected by the ONU. Similarly, the transmission errors occurring in the upstream PON section are repeated as they are and, in conjunction with the transmission errors generated in the PON trunk section, will be corrected by the OLT.

3. Characteristics

This section describes the repeating characteristics of the PON repeater, in particular, the repeating characteristics of the upstream burst signal, which is specific to a PON.

3-1 Repeating characteristics of the upstream optical burst signal

Figure 5 shows the waveform of an upstream 10G optical burst signal relayed from the PON leaf I/F (the ONU) to the trunk I/F (the OLT). When a 10G optical burst signal [1] is received (detection signal turns to low [2]), a dummy signal is inserted in the non-signal section to convert the optical burst signal to an optical pseudo continuous signal [3]. The non-signal section of approximately 250 ns is used for evaluation. It is inserted in the optical pseudo continuous signal after the end of the burst signal to observe a relay delay, which is approximately 270 ns. 580 ns after the beginning of the burst signal [1], the optical pseudo continuous signal [3] changes. This is because the signal pattern changes from a dummy signal to a relay data signal. A section of 310 ns from the beginning of the burst signal, which is the result of subtracting a delay of 270 ns from 580 ns, is replaced with a dummy signal. It is sufficiently shorter than the standard synchronization time from the beginning of the burst signal (1.2 μs for 10G and 800 ns for 1G), which does not affect reception at the OLT.

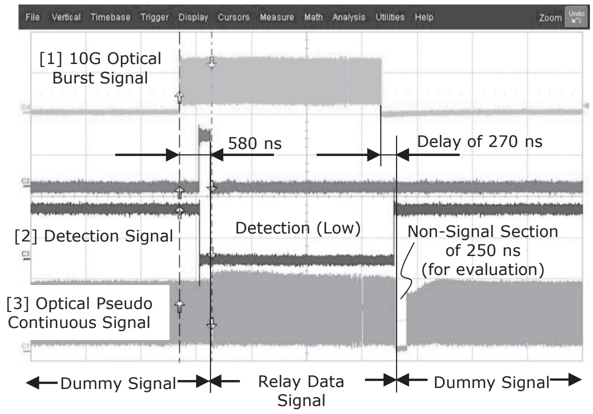


Fig. 5. Sample Relay of an Upstream 10G Optical Burst Signal

3-2 Upstream 10G/1G optical burst reception characteristics of the repeater

The main specifications of the OLT optical transceiver used in the PON leaf I/F of the repeater are shown in Table 2. The sensitivity characteristics of optical burst signal reception are indicated in Fig. 6. The figure demonstrates that the repeater properly detects and receives upstream 10G/1G optical burst signals.

Figure 6 shows the 10G sensitivity characteristics of the optical transceiver by itself [1], the 10G sensitivity characteristics of the optical transceiver installed in the repeater (with error correction) [2], and the 1G sensitivity characteristics of the optical transceiver installed in the repeater [3].

A bit error ratio (BER) of 10^{-3} at a 10G received power of -30 dBm of the optical transceiver by itself [1] is reduced to 10^{-12} by error correction when the optical transceiver is installed in the repeater. In both cases, BERs of -28.0 dBm in the specifications have been achieved. The transmission BER of the optical transceiver installed in the repeater is calculated based on the number of communication frames transmitted from the ONU to the OLT, and the number of discarded frames. During the measurement, the optical received power was adjusted with a variable optical attenuator so that transmission errors occur only in the upstream PON leaf section. Since the repeater has no error correction function, the transmission errors in the 10G signal generated in the PON leaf section will be corrected in the reception process of the OLT.

For the 1G sensitivity characteristics of the optical transceiver installed in the repeater [3], a sufficient margin of approximately 4 dB is obtained for the 1G receiver

Table 2. Repeater PON Leaf I/F Main Specifications of the OLT Optical Transceiver

Item	Specifications
10G Transmitter Output Power	+2.0 to +5.0 dBm
10G Receiver Sensitivity (BER = 10^{-3})	-28.0 to -6.0 dBm
1G Receiver Sensitivity (BER = 10^{-12})	-29.78 to -9.38 dBm

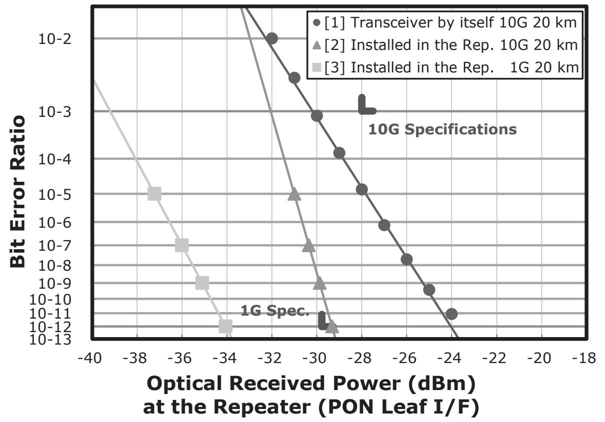


Fig. 6. Reception Sensitivity Characteristics of the PON Leaf I/F of the Repeater

sensitivity of -29.78 dBm at a BER of 10^{-12} in the specifications.

3-3 Upstream 10G/1G optical pseudo continuous signal reception characteristics of the OLT

It has been demonstrated that the OLT properly receives the upstream 10G/1G optical pseudo continuous signal converted by the repeater. Table 3 shows the major specifications of the DWDM optical transceiver used for the transmission and reception in the PON trunk section. The major specifications are common to the repeater and OLT. In 10G signal transmission, the transmission errors occurring in both PON leaf section and PON trunk section are corrected by the OLT (for upstream) or the ONU (for downstream). The allowable BER in the PON leaf section is 10^{-3}, which is the same as in the PON section. The BER of the DWDM optical transceiver used in the PON trunk section is 10^{-5}, which is one hundredth of the BER in the PON leaf section. By specifying a BER sufficiently lower than that in the PON leaf section, the transmission errors in the PON trunk section can be negligible after error correction.

Table 3. Repeater and OLT PON Trunk I/F Main Specifications of the DWDM Optical Transceiver

Item	Specifications
10G/1G Transmitter Output Power	0 to +4 dBm
10G Receiver Sensitivity (BER = 10^{-5})	-26.5 to -7.0 dBm
1G Receiver Sensitivity (BER = 10^{-12})	-26.5 to -7.0 dBm (only upstream)
Wavelength	DWDM 100 GHz grid ch20 to ch35 (1561.42 to 1549.32 nm)

Assuming a fiber loss of 10 to 14 dB in transmission over 40 km and insertion loss of 7 dB (typical) to 10.4 dB (maximum) at the DWDM multiplexing/demultiplexing coupler, with a total maximum loss of 24.4 dB, the transmitter output power and receiver sensitivity of the DWDM optical transceiver were specified to be a budget (difference between the transmitter output power and receiver sensitivity) of 26.5 dB.

Figure 7 shows the sensitivity characteristics of receiving a 10G/1G optical pseudo continuous signal by the OLT. It indicates the 10G sensitivity characteristics of the optical transceiver by itself (in transmission distances of 0 km [1] and 40 km [2]), 10G sensitivity characteristics of the optical transceiver installed in the OLT (in a transmission distance of 40 km [3]) and the 1G sensitivity characteristics (in transmission distances of 0 km [4] and 40 km [5]). The 10G sensitivity characteristics of the optical transceiver by itself [1] and [2] satisfy the specifications in Table 3. The 10G BER of the optical transceiver installed in the OLT [3] is lower than that of the optical transceiver by itself [2], which indicates that the optical pseudo continuous signal is properly error-corrected by the OLT, similar to a normal burst signal.

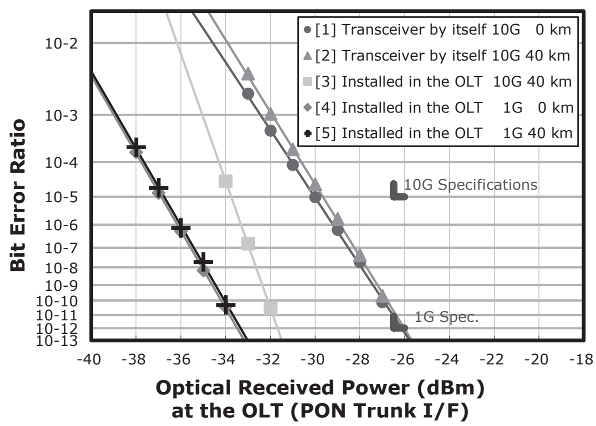


Fig. 7. Reception Sensitivity Characteristics of OLT PON Trunk I/F

For the 1G sensitivity characteristics of the optical transceiver installed in the OLT [4] and [5], there are sufficient margins for the 1G receiver sensitivity of -26.5 dBm at a BER of 10^{-12} in the specifications, which provides budget required for 40 km transmission.

4. Conclusion

This paper has described a wavelength multiplex repeater for a 10G-EPON system. We believe that it will contribute to the development of access networks by extending the communication distance between the OLT and ONU, accommodating more subscribers, and improving the efficiency of transmission using the fibers in the PON trunk section.

• Ethernet is a trademark or registered trademark of Xerox Corporation.

Technical Terms

*1 GE-PON and 10G-EPON: These are the PON systems specified in the IEEE802.3 standard.(3) Gigabit-Ethernet PON (GE-PON) has a transmission capacity of 1 Gbits/s and 10Gigabit-Ethernet PON (10G-EPON) has a transmission capacity of 10 Gbit/s.

*2 Wavelength division multiplexing (WDM): This is a transmission technology for multiplexing several optical signals with different wavelengths in a single optical fiber. Optical signals are mixed and separated with an optical multiplex/demultiplex coupler.

*3 Downstream and upstream optical signals: A downstream signal is carried from the OLT to the ONU, and an upstream signal is carried in the opposite direction.

*4 Burst signal: This is an upstream signal transmitted from each ONU by time-division multiplexing or intermittently (in bursts) so that it can avoid collisions with others.

*5 Clock and data recovery (CDR) circuit: This circuit extracts a clock signal from a data signal while regenerating the data signal using the clock signal. This process eliminates timing fluctuations.

References

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(3) IEEE Std. 802.3-2012

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