Large-Capacity Optical Transmission Technologies Supporting the Optical Submarine Cable System

INOUE Takanori

Abstract

As one of the foundations of the global network, the submarine cable system is required to achieve large-capacity transmissions of the Tbps class and long-distance transmissions at the transpacific level and both of these at high quality. This paper describes the technology for achieving long-distance transmissions and the associated efforts being applied by NEC.

Keywords

dispersion-managed fiber, RZ-DPSK, RZ-DQPSK, 40-Gbps system, transmission experiment

1. Introduction

As a result of the application of multiple technologies including direct optical amplification, optical fiber transmission line design, high-sensitivity optical modems, high-density Wavelength Division Multiplexing (WDM) technologies, the optical submarine cable system for use in transoceanic communications has now put large-capacity transmissions of over 1 Tbps per fiber to practical use. Such large capacity is made possible by the 10-Gbps wavelength division multiplexing transmission method. However, the 40-Gbps-class method is currently waited to increase the capacity further. This paper introduces the efforts of NEC that are related to the large-capacity, long-distance optical transmission technologies supporting the optical submarine cable system.

2. 10-Gbps Waveform Wavelength Multiplexed Transmission

This section deals with the main constituent technologies of the 10-Gbps wavelength division multiplexing transmission method used as the mainstream of the current optical submarine cable system and introduces an example of ultra long-distance, large-capacity transmission characteristics that will be made possible by applying these technologies.

2.1 Broadband, Low-noise Direct Optical Amplification Technology

The optical signals propagated via the transmission line are subjected to repeated attenuations due to optical fiber loss and repeated amplifications by the optical submarine repeaters that are installed at constant intervals. To increase the capacity of the optical submarine cable system, it is required to provide the optical submarine repeaters with wider bandwidths and flat gain characteristics so that more signals can be transmitted with a wavelength division multiplexing system. In addition, in the case of long-distance transmissions, since the optical submarine repeaters are connected in multiple stages and the amplified spontaneous emission noise produced by them are accumulated, it is also important to reduce their noise figure and to achieve a high OSNR (Optical Signal to Noise Ratio) at the receiving end.

The optical submarine repeater of NEC features a flat gain characteristic over a wide bandwidth of 36 nm or more and a low noise figure of less than 4.5 dB. It thereby offers a broadband, low-noise direct optical amplification suitable for large-capacity, long-distance transmission of optical signals.

2.2 Ultra-high Density Wavelength Division Multiplexing Technology and High-gain forward Error Correction Technology

Of importance in increasing the capacity of the optical submarine cable system is to increase the number of signals in the signal bandwidth by decreasing the intervals between adjacent signal wavelengths and to increase the gain of the FEC (Forward Error Correction) that corrects the code errors caused due to optical signal waveform degradation and OSNR degradation.

The optical submarine terminal equipment of NEC is capable of ultra high-density wavelength division multiplexing at channel spacing of 33.3 GHz and 25 GHz, and equipped with a high-gain FEC, which is capable of correcting a signal with 3.3×10^{-3} BER (Bit Error Rate) to an error-free signal with below 1×10^{-12} BER.

2.3 Dispersion-managed Transmission Line Technology

To reduce waveform distortion due to the composite result the chromatic dispersion and the nonlinear optical effects in long-distance optical transmission, it is effective to design the transmission line so that the chromatic dispersion of the overall system is reduced while maintaining local chromatic dispersions. In addition, in order to deal with the expansion of transmission bandwidths following the introduction of the high-density wavelength division multiplexing technology, it is important to render the dispersion characteristic flat all over the transmission bandwidth by minimizing the dispersion slope. In order to enable such improvement, NEC is applying the DMF (Dispersion Managed Fiber) using two kinds of optical fiber with different characteristics for the long-distance optical submarine cable system.

Fig. 1 shows an example of repeating span using a dispersion-managed fiber. The dispersion-managed fiber consists of a positive-dispersion fiber and a negative-dispersion fiber: the positive-dispersion fiber has a positive dispersion value and slope (hereinafter expressed as D+), and the negative-dispersion fiber has the reverse sign to the D+ fiber and about twice the chromatic dispersion and dispersion slope of the D+ fiber (hereinafter expressed as D-). Setting the ratio between the D + fiber length and the D- fiber length to 2:1 makes it possible to almost nullify the chromatic dispersion and dispersion slope of the overall system. In addition, the D+ fiber with an enlarged effective area is connected to the section with high signal intensity. This takes place immediately after each optical submarine repeater. The D- fiber with a small effective area is connected to the end section of the fiber where the signal intensity starts attenuation. Thus, the influence of the nonlinear effect is reduced.

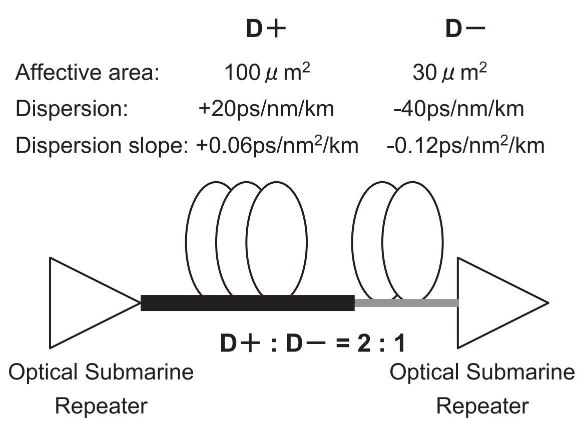


Fig. 1 Example of dispersion-managed fiber configuration.

2.4 High-sensitivity RZ-DPSK Modulation Technology

In the case of long-distance transmission using multiple stages of optical submarine repeaters, high receiver sensitivity is necessary to obtain sufficient transmission characteristics, even under conditions with low receiving-end OSNR. The modulation format used generally in traditional optical submarine cable systems is the OOK (On-Off Keying) modulation format that utilizes optical intensity information such as NRZ (Non-Return-to-Zero) and RZ (Return-to-Zero). In addition, the RZ-DPSK (Return-to-Zero Differential Phase Shift Keying) modulation format that utilizes the optical phase information has been put to practical use more recently.

With the RZ-DPSK modulation format, the transmitter side superimposes the send data in the form of phase difference information, and the receiver side applies 1-bit delayed interference to the optical signal. This optical signal is detected by a balanced receiver to convert the phase information into an electrical signal having twice the signal amplitude. The optical signal is thus demodulated into the data string. As a result, the RZ-DPSK modulation format can offer an about 3 dB higher receiver sensitivity characteristic compared to the traditional RZ modulation format. This reduces the degradation in the receiving-end OSNR due to the multi-stage connections of the optical submarine repeaters by 3 dB, thus making it possible to extend the transmission distance by about twice when the repeater spacing is the same. In addition, the RZ-DPSK modulation format is more tolerant of nonlinear effects than the traditional RZ modulation format and it is therefore more suitable for long-distance transmissions.

NEC has lined up the NRZ, RZ and RZ-DSPK modulation format for use in 10-Gbps transmission systems in order to enable the selection of an appropriate solution according to the transmission capacity and distance requirements.

2.5 Examples of Ultra-long Distance, Large-capacity Transmission

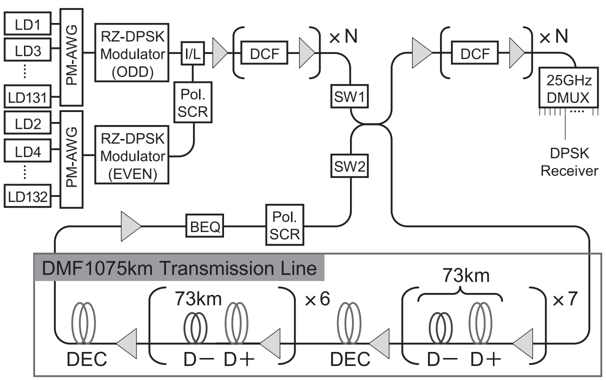
NEC has built optical transmission characteristic evaluation systems by combining optical transceivers, optical amplifiers and optical fiber transmission line by applying the technologies described above. We are presently conducting assessment and verification of various transmission performances. In the rest of this section, as an example obtained with optical transmission characteristic evaluation systems, we will introduce the transmission characteristics of an ultra long-distance transmission system with a large capacity over 1 Tbps.

Fig. 2 (a) shows the configuration of a 10-Gbps/132-wave (1.32 Tbps) optical transmission characteristic evaluation system.

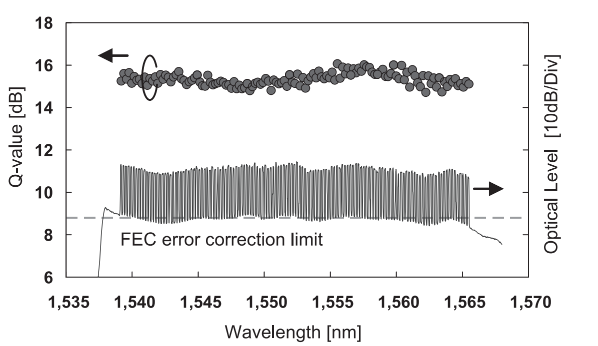
The transmitter side generates a 132-wave/10-Gbps RZ-DPSK signal with a 25-GHz channel spacing using two RZ-DPSK modulators and transmits it to the transmission line through DCFs (Dispersion Compensation Fiber) for pre-dispersion compensation. The re-circulating loop has a total length of 1,075 km, which is composed of DMF fibers with a 73 km span, DEC (Dispersion Equalization Cable) for in-line dispersion compensation, optical repeaters with +16.4-dBm output power, a 28-nm signal bandwidth and BEQs (Block Equalization). The signal received from the transmission line is sent via a DCF to compensate for the accumulate dispersion and then to a 25 GHz De-MUX to extract only the desired signal wavelength and is eventually input to a RZ-DPSK demodulator.

Fig. 2(b) shows the Q-value and received optical spectrum after 6,450 km transmission. The X-axis represents the wavelength, and the Y-axis represents the Q-value at the left edge and the optical level of the received optical spectrum on the right edge. The figure shows a good transmission characteristic, in which a margin of 6 dB or more is assured for the FEC error correction limit Q-value of 8.8 dB even with a signal wavelength having the worst Q-value characteristic.

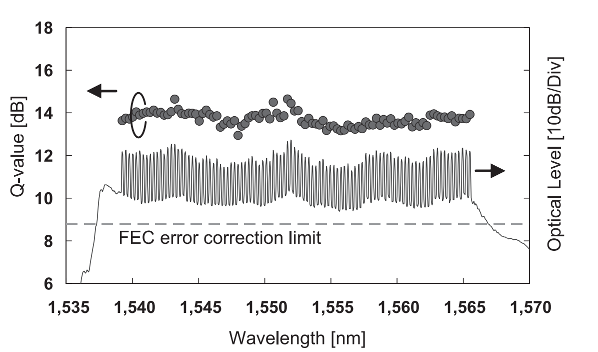
Fig. 2(c) shows the result of evaluation of the transmission characteristic of a transmission over 9,675 km of a RZ-DPSK signal with 99 waves in a 33-GHz channel spacing. This has been measured by changing only the optical transceiver configuration. The figure shows the existence of a margin of 4 dB or more for the FEC error correction limit even at the signal wavelength with the worst Q-value. This result indicates the possibility of high-quality, large-capacity transmission via an optical submarine cable system with a distance corresponding to transpacific transmission.



(a) 10-Gbps/132-wave transmission experiment setup



(b) 10-Gbps/132-wave/6,450-km transmission characteristic



(c) 10-Gbps/99-wave/9,675-km transmission characteristic

Fig. 2 Examples of transmission characteristics of 10-Gbps/132-wave/6,450-km and 10-Gps/99-wave/9,675-km transmissions.

3. 40–Gbps Wavelength Division Multiplexing Transmission technologies

Since the number of signal wavelengths that can be multiplexed in the limited signal bandwidth of optical submarine repeaters, an increase in the signal bit rate is an effective means for increasing the transmission capacity. Based on the increased dissemination of 40-Gbps transmission systems in

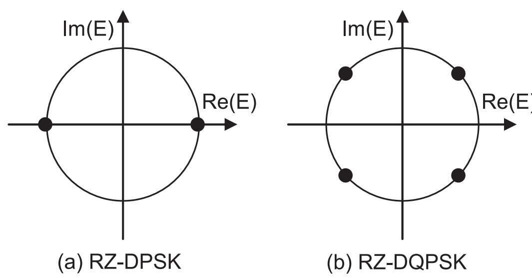


Fig. 3 Constellations of RZ-DPSK and RZ-DQPSK modulated signals.

terrestrial communication networks expectations for their introduction in the field of optical submarine cable system is also increasing. By responding to market expectations and in order to promote the 40G optical submarine cable system, we are developing a 40-Gbps wavelength division multiplexing transmission technologies. This applies the RZ-DQPSK (Return-to-Zero Differential Quadrature Phase Shift Keying) modulation format for larger capacities in addition to the RZ-DPSK modulation format.

3.1 RZ-DPSK and RZ-DQPSK Modulation Format

Fig. 3 shows the constellations (complex electric field distributions) of the RZ-DPSK and RZ-DQPSK modulation formats. While the RZ-DPSK modulation format superimposes information data in binary phase data, the RZ-DQPSK modulation format superimposes it in the TT/2 shifted quadruple phase data, which enables transmission of 2 bits of information per symbol. The result is that the RZ-DQPSK modulation format can reduce the symbol rate to 20 Gbps in spite of the 40-Gbps bit rate. When it is assumed that the same signal bandwidth as the 10-Gbps transmission system with a 25-GHz channel spacing is used, the transmission capacity of the RZ-DPSK modulation format with a 40-Gbps symbol rate remains the same because the channel spacing is limited to 100 GHz. However, the capacity of the RZ-DQPSK modulation format with half the symbol rate can be doubled because the channel spacing can be reduced to 50 GHz.

3.2 Transmission Characteristic Examples of 40-Gbps RZ-DPSK/RZ-DQPSK Modulation Formats

To optimize the applications of the RZ-DPSK and RZ-DQPSK modulation formats, we have evaluated the transmission characteristics of the two formats using a 4,300-km

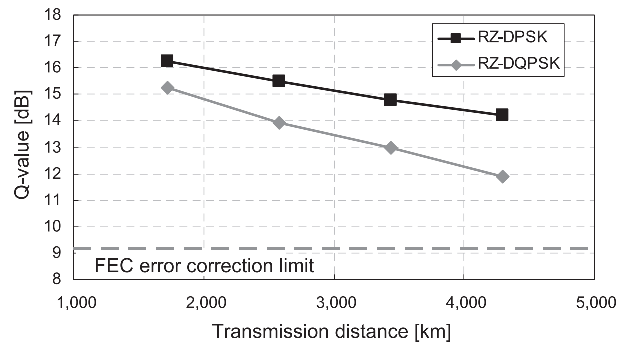


Fig. 4 Transmission distance versus Q-Value of 40-Gbps signals.

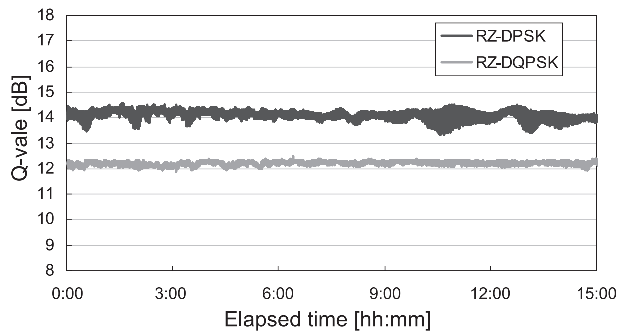


Fig. 5 Long-term stability after a 4,300-km transmission of 40 Gbps signals.

transmission line.

Fig. 4 shows the transmission distance versus the Q-value characteristics of two types of modulated signals; a 40-Gbps RZ-DPSK (return-to-zero differential phase shift keying) and a 40-Gbps RZ-DQPSK (Return-to-Zero Differential Quadrature Phase Shift Keying). A 40-Gbps RZ-DPSK modulated signal is multiplexed with a WDM system at a 100-GHz channel spacing, and a 40-Gbps RZ-DQPSK modulated signals is transmitted at a 50-GHz channel spacing. The X-axis represents the transmission distance and the Y-axis represents the Q-value. The transmission line is a DMF straight line path with 43-km repeater spacing, and the average dispersion of the system is adjusted in order to obtain the optimum transmission characteristic of each modulation format. The figure shows that the RZ-DPSK modulated signal can provide a higher transmission characteristic at any transmission distance. This may be because the RZ-DPSK modulation format has a higher tolerance of nonlinearity as well as of waveform distortion due to phase noise.

Fig. 5 shows the results of the long-term stability measurements of signals after the 4,300-km transmissions of the two modulation formats. The X-axis represents the time elapsed from the measurement start time, the Y-axis represents the Q-value and the graph plots the Q-values that are measured continuously. The standard deviations, which are the indices of stability, are 0.15 dB with the RZ-DPSK signal and 0.07 dB with the RZ-DQPSK. The fluctuation is slightly greater with the RZ-DPSK signal that uses a 40-Gbps symbol rate. The results show that both modulation formats have sufficient stability for use as commercial systems.

As seen above, the RZ-DPSK modulation format is superior from the viewpoint of the Q-value after transmission, while the RZ-DQPSK modulation format is superior from the viewpoint of transmission capacity. We therefore offer the appropriate solution that can make full use of the advantage of each modulation format by considering the requirements of each system.

4. Conclusion

NEC has already put optical submarine cable systems into practical use based on the 10-Gbps wavelength division multiplexing technologies that offer transmission capacities over 1 Tbps. In the future, we intend to develop practical optical transmission technologies for ultra-high speeds of 40 Gbps or more in order to deal with further increases in the capacity of the global network.

Author's Profile

INOUE Takanori
Assistant Manager
Submarine Network Division
Broadband Networks Operations Unit
NEC Corporation