Large-Capacity Optical Transmission Technology Supporting Optical Submarine Cable Systems

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Abstract

The optical submarine cable system that connects the countries of the world via optical fibers plays an important infrastructure role in supporting international communications networks. This paper introduces the latest optical submarine cable system and outlines its major components, such as the digital coherent terminal equipment, submarine transmission line, submarine repeater and submarine branching unit. We also discuss technical trends that are aimed at future increases in capacity.

Keywords

optical submarine cable system, digital coherent technology, submarine transmission line, submarine repeater, submarine branching unit

1. Introduction

The submarine cable system has a long history. At NEC, we began submarine cable system business in 1968 and have supplied a large number of installations since that time.

Fig. 1 shows the transition of technologies related to the submarine cable system since 1970. After shifting from coaxial cables to optical cables in the eighties, the introduction of the direct optical amplification technology in the nineties has led to a significant increase in the transmission capacity based on combination with wavelength multiplexing. This has made the submarine system an essential infrastructure for international communications. In addition, after the practical use of digital coherent technology since 2010, the possibility of compensating for most of the transmission line signal degradation has brought about an important change in the configuration of optical submarine cable systems. Below, we introduce the optical submarine cable system of the digital coherent age and discuss the optical transmission technology and the equipment that support it.

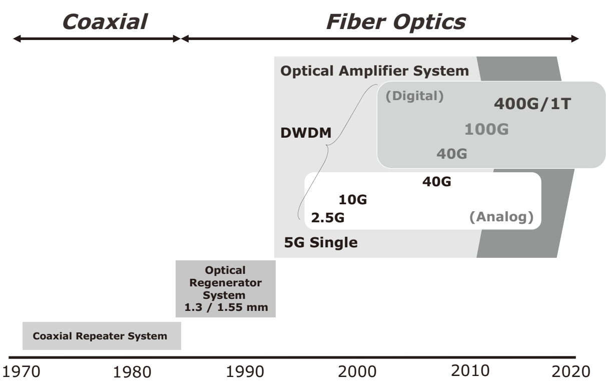

Fig. 1 Transition of the submarine cable systems technologies.

2. Present Optical Submarine Cable System

Fig. 2 shows progress in the transmission capacity of the optical submarine cable systems and their key technologies enabled by direct optical amplification. The optical submarine cable system has been increasing its transmission capacity significantly over the recent five

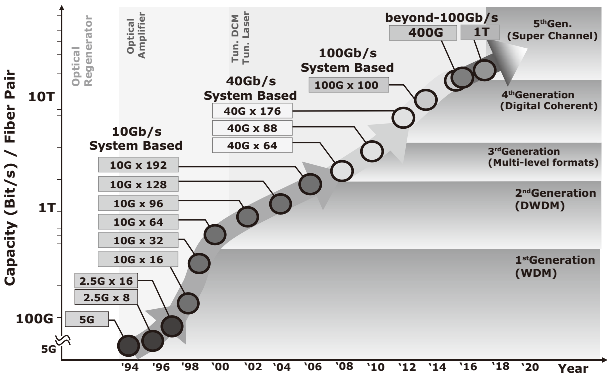

Fig. 2 Progress of transmission capacity.

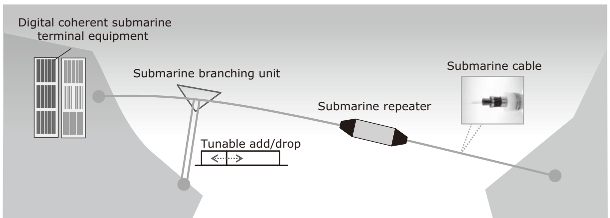

Fig. 3 General configuration of submarine cable systems.

years. Wavelength-multiplexed transmission with a capacity as large as 10 Tbps is now possible per fiber pair (100 Gbps – 100 waves). The key technology involved in this increase in the transmission capacity is the digital coherent technology, which is capable of electrical compensation based on the digital processing of the signal degradation that is produced linearly in optical fiber transmissions.

As a result, the restriction imposed by chromatic dispersion inside the optical fibers, which used to be a factor imposing limits on the transmission distance, has theoretically been eliminated. Consequently, optical signals can now not only increase the speed and capacity but will also allow the optical signal route to be changed easily.

Fig. 3 shows an example of the configuration of an optical submarine cable system. This example installs digital coherent transponders as the transmission terminal equipment of the landing stations. It also places submarine repeaters incorporating Er^{3+} doped optical amplifiers and optical fibers featuring low loss and enlarged effective core cross-sections alternatively on the transmission lines. As the whole of the chromatic dispersion accumulated in the transmission line is basically compensated for by the digital signal processing in the transponders, management of the chromatic dispersion in the transmission lines become entirely unnecessary. This innovation is the biggest change from the traditional transmission lines that has been brought about by the introduction of the digital coherent technology.

The submarine branching unit branches the submarine cables. It not only switches the power feed path but additionally is currently incorporating the ROADM (Reconfigurable Optical Add/Drop Multiplexer) function that can switch the optical signal path on a per-wavelength basis. Switching the path of optical signals alters the transmission distance and, as a result, varies the amount of accumulated chromatic dispersion. With the digital coherent system, the amount of dispersion compensation can be optimized adaptively so that the dynamic ROADM function can be implemented, even for optical submarine cables.

The technology described above has made it possible to provide an ultra-long-distance submarine cable system of the transpacific class with the large capacity of max. 80 Tbps (10 Tbs-8 fiber pairs) as well as enabling flexible ROADM networking.

Below, we will discuss the main components and technologies that support the latest submarine cable systems.

3. Main Components of the Optical Submarine Cable Systems

3.1 Digital Coherent Submarine Terminal Equipment

Photo 1 shows the 100 Gbps submarine terminal equipment applying the digital coherent technology. The terminal equipment is composed of the transponder block (left in Photo 1) and the wavelength division multiplexing/de-multiplexing block (right in Photo 1).

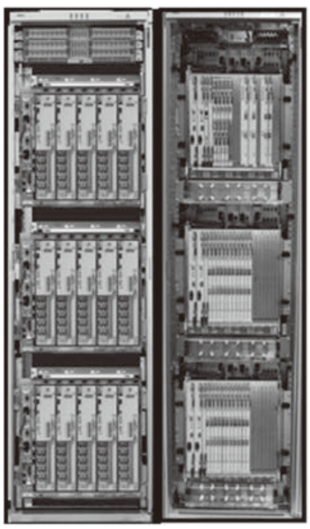

Photo 1 100 Gbps submarine terminal equipment.

The transponder block incorporates an optical transceiver applying the digital coherent technology. At the same time as transmitting and receiving the polarization multiplexed optical signal at 100 Gbps per wavelength it compensates for the waveform degradation produced in the optical fiber transmission line by means of electrical processing. It also corrects the coding error so that high-quality communications are possible, even in an ultra-long-distance transmission of the transpacific class. The wavelength division multiplexing/de-multiplexing performs the wavelength division multiplexing/de-multiplexing of the optical signal in each transponder into as many as 100 wavelengths. It also transmits and receives the submarine equipment monitoring/control signals.

3.2 Submarine Transmission Line

The introduction of the digital coherent technology has changed the performance requirements for the optical fibers used in the transmission lines of submarine cable systems. Before the introduction of the digital coherent technology, the transmission lines were generally designed by considering the chromatic dispersion characteristics of the optical fiber, so that the accumulated chromatic dispersion became null.

Fig. 4 shows the change of chromatic dispersion map design for the submarine transmission line. In the age of the 10 Gbps OOK (On-Off Keying) method, the Non-Zero-Dispersion Shifted Fiber (NZDSF) and Dispersion Compensation Fiber (DCF) have been used to compensate for the chromatic dispersion accumulated in the NZDSF transmission line with the DCFs installed at periodic intervals. Compensation for the final residual chromatic dispersion of each wavelength in the terminal equipment is also of importance. Since then, the DMF (Dispersion Management Fiber) was introduced. DMF combines optical fibers with positive dispersion values and ones with negative dispersion values in a specific ratio, and allocates them in each transmission span. This has enabled more advanced dispersion management, allowing the system to be used as a transmission line for the 40 Gbps high-speed signals. The transmission lines with chromatic dispersion management have come to need advanced maintenance in consideration of the dispersion design when repair is undertaken on a submarine cable that has been disconnected by a submarine earthquake, etc.

On the other hand, the introduction of the digital coherent technology has now made the chromatic dispersion management of the transmission line superfluous. The present systems employ simple chromatic dispersion map designs as shown in Fig. 4 (top right) so that the maintenance and servicing are performed more easily. Optical fibers are also tending to improve performance by focusing on reductions in the loss and nonlinearity.

3.3 Submarine Repeaters

Following the introduction of direct optical amplification in the nineties, submarine repeaters began to incorporate Er^{3+} doped optical amplifiers and have achieved excellent optical characteristics. These included broad bandwidth, high output power and low noise, which are important in large-capacity transmissions and feature high reliability. **Photo 2** shows a submarine repeater and **Fig. 5** shows an example of measurement of the spectral characteristics of the optical output signal when a wavelength multi-

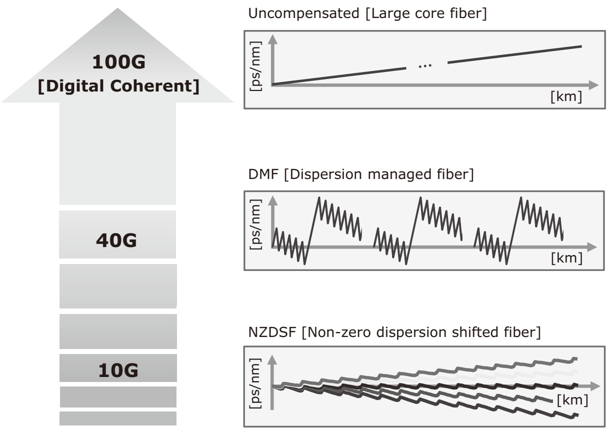

Fig. 4 Change of waveform dispersion map design for submarine transmission lines.

Photo 2 Submarine repeater.

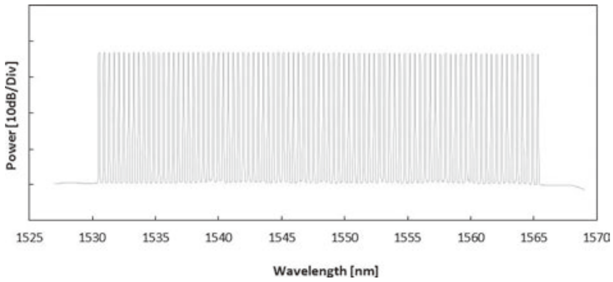

Fig. 5 Example of the spectral characteristic of optical output from a submarine repeater.

plexed signal is input to a submarine repeater. The highly accurate gain equalization technology provides a gain flatness characteristic with inter-signal gain deviation below 0.1 dB across a signal amplification band of 36 nm or more. This excellent gain flatness characteristic makes it possible to provide high-quality, uniform transmission characteristic between different wavelengths in the band, even with a transpacific class submarine cable system, in which more than 100 submarine repeaters are connected in multiple steps.

3.4 Submarine Branching Unit

In order to connect several countries and regions efficiently, a submarine cable system branches the submarine cables using submarine branching units. **Photo 3** shows a submarine branching unit. This device branches the optical fiber transmission and power feed lines of a single cable into those of two cables.

The power for the submarine repeaters and branching unit is supplied from the power feed equipment installed in the landing stations. The submarine branching unit switches the power feed path under remote control from the landing station. Switching the power feed path in the case of a cable fault can minimize effects on the network circuits.

Recent submarine cable systems have begun to introduce the ROADM function that is disseminated among terrestrial systems. **Fig. 6** shows the current mainstream device of the submarine ROADM function.

With the currently used submarine ROADM systems, several wavelength filters are incorporated in the submarine branching units and these are selected according to changes in the circuit demand by sending a remote control signal from the landing station. In the future with the aim of further improving flexibility, it is expected that technologies such as the Wavelength Selectable Switch (WSS) will be introduced in the submarine systems, just as in the terrestrial systems.

Photo 3 Submarine branching unit.

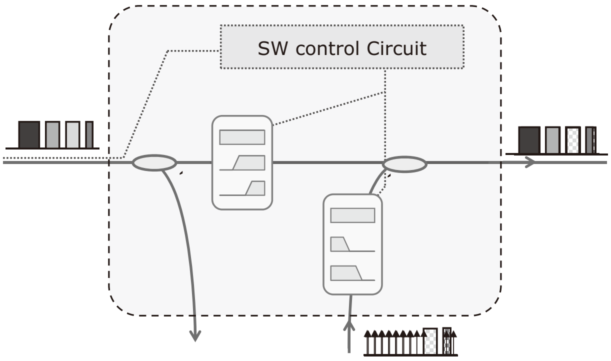

Fig. 6 ROADM function of submarine branching unit.

4. Future Technology Trends

In order to support the continually growing international traffic demands the optical submarine cable systems of the future will be required to increase the transmission capacity even further.

Fig. 7 shows the key technologies being studied in order to increase the transmission capacities. The aim in the technological field related to the transponder is to increase the spectral efficiencies by introducing high-order multilevel modulation. It is also hoped to improve the transmission quality by improving the compensation capability of the linear/nonlinear impairments produced in the transmission lines by improving the coding error rate correction gain. The aim for the technological fields related to the submarine transmission lines is to expand the amplification bandwidth of the repeaters and to increase the signal wavelengths by adopting multi-core optical fibers. In the future we will challenge the development of these technologies with the aim of increasing the capacity of the optical submarine cable systems.

5. Conclusion

The optical submarine cable system has already become an essential network infrastructure for supporting the current international communications systems. Based on our experience and achievements accumulated over more than forty years, NEC intends to continue to advance the technological development of the system. It

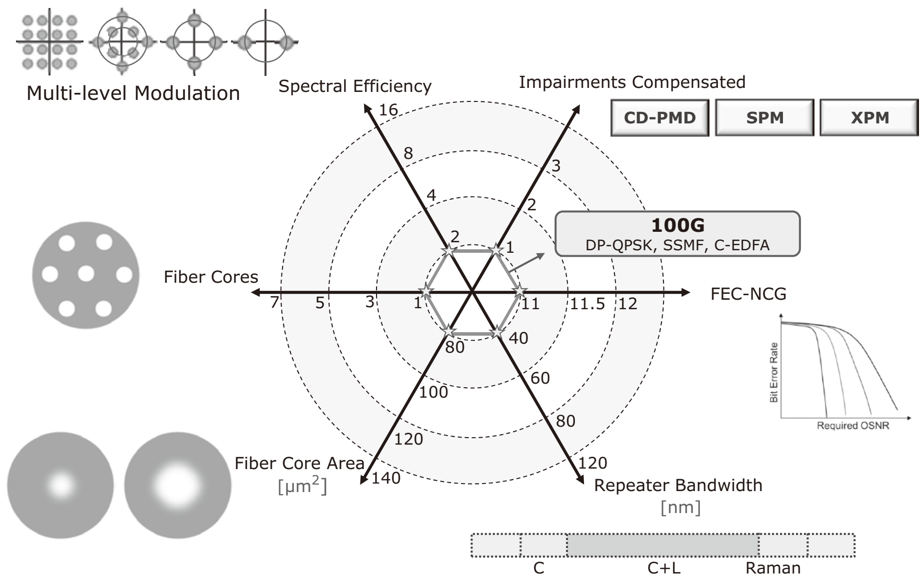

Fig. 7 Key technologies being studied for increasing the transmission capacities.

will thereby contribute to improving the networks interconnecting the countries of the world by providing even more advanced optical submarine cable systems.

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