Construction Technology for Use in Repeated Transoceanic Optical Submarine Cable Systems

YONEYAMA Kenichi, SAKUYAMA Hiroshi, HAGISAWA Akira

Abstract

In terms of capacity, distance and number of connecting points, the requirements for submarine cable systems have been increasing every year. The key to the implementation of the most advanced ultra-long distance transoceanic submarine cable system of large capacity lies in how to introduce and apply the latest optical signaling technology to the actual systems design and construction. This paper introduces the construction technologies that are being applied to large-capacity, ultra-long distance submarine cable systems from the perspectives of system design, equipment fabrication, system assembly and system construction.

Keywords

submarine cable, systems, system construction, gain equalization, dispersion equalization

1. Introduction

Following the rapid increase of image distribution in the Internet environment and its increased speed, the demands of communication traffic have been growing every year. In response to the traffic demand for international communications, innovative technologies, aimed at increasing the capacity of long-distance optical signal transmission systems, are being researched and developed continuously. Optical submarine cables applying these latest technologies are being planned and constructed one after another.

2. Processes of Submarine Cable System Construction

Fig. 1 shows an example of the process of submarine cable system construction.

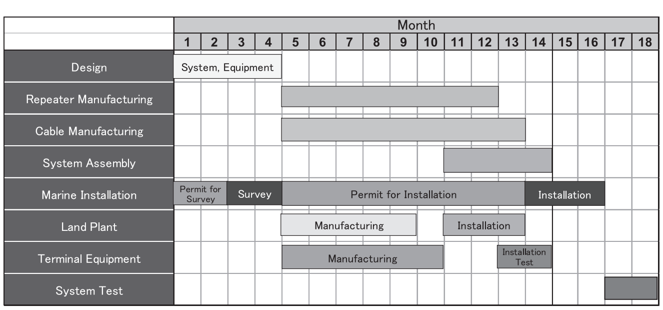

Fig. 1 Process of submarine cable system construction.

A submarine cable system is constructed using processes that include system design, equipment design/manufacturing, assembly/testing of the submarine equipment by connecting submarine cables and submarine repeaters, constructing submarine plant using cable ships, installing terminating equipment, constructing land plants and performing system testing. The period required from design to completion of a submarine cable system is about a year for a small-scale system or two years in the case of a large-scale system.

3. System Design

The system design work required for a submarine cable system includes the submarine plant design, optical signal performance design, the power feeding design, monitoring network design and other (marine, land and in-station) designs.

3.1 Submarine Plant Design

Initially, a straight line diagram (SLD) showing the configuration of the submarine plant is drawn up based on the cable route and the marine chart information. The type of each submarine cable to be utilized is decided based on the sea depth and the geological context of its location and these functions are reflected in the SLD. **Fig. 2** shows the types of submarine cables and the depths at which they may be applied. The SLD also outlines the positions of the submarine repeaters, the joint box (JB) information and the land cable lengths. The intervals of the submarine repeaters (repeater span) are decided at

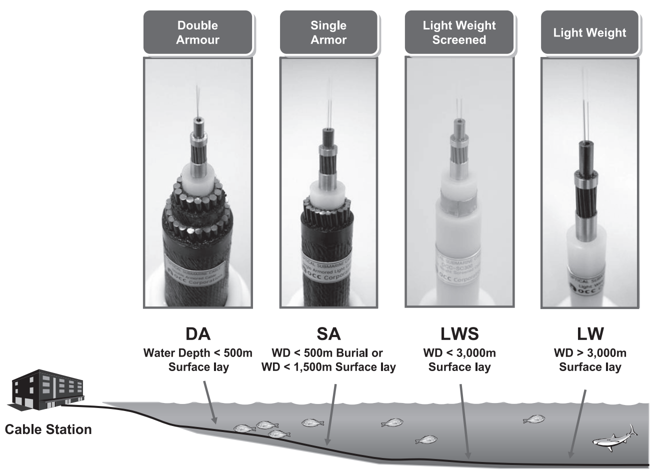

Fig. 2 Submarine cable types and applicable depths.

the optical signal performance design stage, because they affect the optical signal transmission performance. The SLD is updated sequentially by feeding back the results of the marine surveys and by the sequence of work.

3.2 Main Signal Performance Design

The optical signal performance is designed based on the cable length, specified in the SLD. The technical trend of optical signal transmission is the wavelength-division multiplexing of 10-Gbps optical signals. The optical signal performance is designed by considering; the cable length, the loss of optical fibers, the optical output power and noise figure (NF) of submarine repeaters, the number of multiplexed wavelengths, the performance of the 10-Gbps optical transceivers, the quality degradation, due to transmission of optical signals (transmission penalty), the manufacturing margins of the equipment and systems and the repair margin according to the service life. In this step, the intervals of the submarine repeaters are adjusted to preserve the required transmission quality and manifacturing/repair margins. Decreasing the repeater intervals improves the signal to noise ratio (SNR) of the optical signals and makes it possible to preserve the margins, but it also increases the number of repeaters and the system cost. It is therefore required to select the longest possible repeater intervals, so far as they can preserve the desirable system margins.

Table shows an example of optical signal performance design (power budget) for a 10-Gbps × 96-wave, 9,000-km system. The optical signal design uses the Q-value, which is the signal quality index generally used in the submarine systems industry.

Table Example of the main signal performance design (power budget).

Item		Value
System length		9,000 km
10-Gbps signal multiplexing		96 waves
1	Theoretical transmission performance (Q-value)	16.0 dB
2	Transmission penalty/stability	3.2 dB
3	Equipment/system manufacturing margin	1.6 dB
4	Repair margin	1.4 dB
5	System margin	1.0 dB
6	System performance limit (1-2-3-4-5)	8.8 dB

3.3 Power Feed Design

The power feeding equipment (PFE) is installed in the landing station to supply power to the submarine repeaters, using the power feeding line located in the submarine cable. Each submarine plant has multiple submarine repeaters connected in series. These are powered by a 1.1-ampere regulated current from the PFE. The resistance of the submarine cable is about 0.8 Ω/km. The voltage may drop due to; the submarine repeaters, the earth potential difference between the landing points (variable between about 0 to 0.3 v/km depending on regions) and due to the insertion of spare repeaters and/or spare cables. A power feeding voltage of about 11 kV is thus required for a system with a length of 9,000 km and a four fiber pair arrangement.

The power is supplied by using a redundant configuration with a dual-end power feeding capability, in which PFE is installed in the stations at both ends of the system. One PFE feeds positive voltage while the other feeds negative voltage, so that each PFE feeds half of the required voltage. Even when either PFE needs to be serviced due to a fault, the system operation can be continued because the other PFE can feed all of the voltage required by the system (single-end power feeding system).

3.4 Monitoring Network Design

Each landing station of the submarine cable system features Element Management System (EMS) that monitor both the system and its various equipments. The EMS in the two

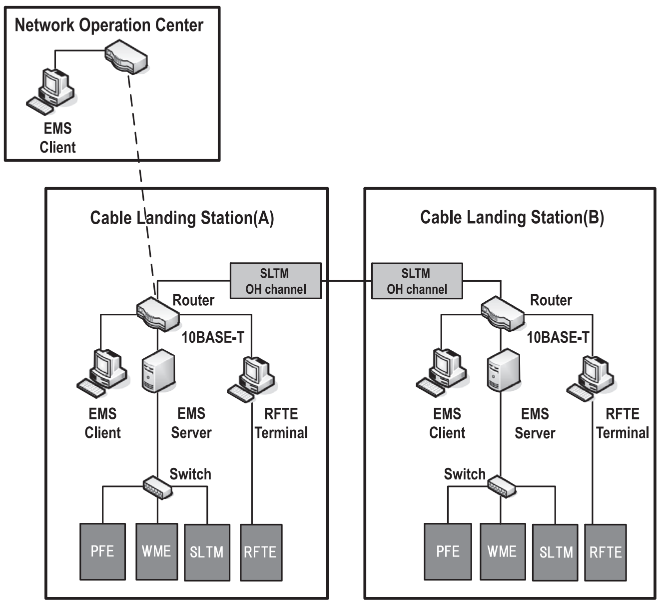

Fig. 3 Example of monitoring network design.

stations are interconnected via an order-wire channel that utilizes the overhead of the 10-Gbps optical signal of the submarine line terminating equipment (SLTE) so that the EMS at one station can also monitor the equipment status of the other station.

Fig. 3 shows an example of a monitoring network configuration for a submarine cable system. The server and client terminal of the EMS are connected to a router at the station, and the router is connected to the order wire channel of the 10-Gbps SLTE, which is subsequently connected to the router at the other station as well as to its EMS server and client. Connecting the landing stations to a remote monitoring center at a distant location via exclusive lines and networks allows the client terminal at the remote monitoring station to monitor the status of the landing stations and of the submarine plant.

4. Detailed Submarine Plant Design and System Adjustment Technologies

The submarine plant of a large-capacity ultra-long distance submarine cable system requires a high-accuracy gain equalization technology in order to achieve the uniform transmission of wavelength-division multiplexed signals without any decrease in their levels. This function is needed even when a large number of repeaters are used and the dispersion management technology for ultra-long distance transmission of high-density wavelength-division multiplexed signals without transmission penalties is applied.

4.1 Gain Equalization Technology

With a 10-Gbps × 96-wave, 9,000-km system, it is necessary to connect about 130 No. 28-nm optical amplification band submarine repeaters in series. As the requirements of gain flatness within the amplification bandwidth for the overall system is only about 8 dB, the gain flatness of the submarine repeaters is required to be very accurate. In addition, the loss of the optical fibers in the submarine cables has a slight wavelength dependency and its effect is not ignorable. Therefore, the shape of the amplification bandwidth of submarine repeaters should be designed in consideration of the wavelength dependency of the optical fiber loss, so that the amplification bandwidth in each repeated section is flat.

During the actual manufacturing process, the accuracy to gain flatness of the submarine repeaters and submarine cables is restricted, which often causes errors in the actual system, making it hard to achieve the optimum gain flatness required for a 9,000-km system. This issue is solved by compensating the accumulated gain flatness errors by inserting gain equalizers in the submarine equipment assembly process and by connecting the submarine repeaters to the submarine cables.

Fig. 4 -A) shows the concept of gain equalization. The gain equalizers include the shape equalizer for correcting the accumulated amplification bandwidth fluctuations and the tilt

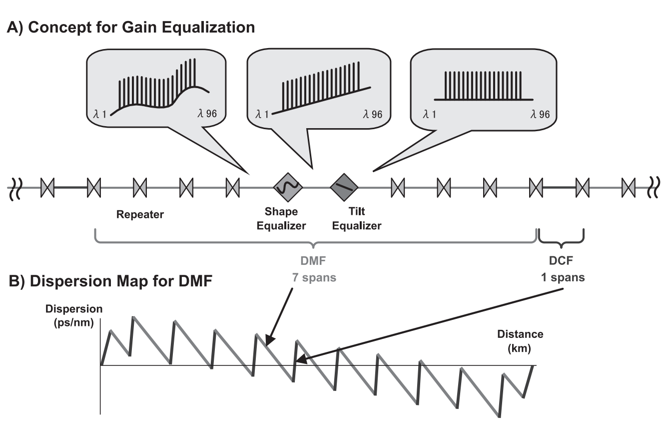

Fig. 4 Gain equalization and dispersion management of submarine plant.

equalizer for correcting the tilts inside the amplification bandwidth. The shape equalizers are designed and fabricated by simulating the error shape based on the gain shapes of the amplification bandwidth of the submarine repeaters and are inserted after every optimum number of repeaters. The tilt equalizers are inserted after the selected shape equalizers with optimum tilts according to the characteristics of the actually manufactured repeaters and cables.

4.2 Dispersion Management Technology

Fig. 4-B) shows an example of a dispersion map, specifically of the dispersion management fibers (DMF) applied to a 10-Gbps × 96-wave, 9,000-km system. Optical fibers with both positive and negative wavelength dispersions are combined in the repeatered sections so that the aggregate dispersion value of each repeatered section is slightly negative. The negative dispersion accumulated due to multiple repeaters' spans is corrected in the dispersion compensation sections that are inserted after each optimum number of repeaters.

Here, too, the dispersion value of the optical fibers in each repeater's span shall be restrictedly controlled during the actual manufacturing process. Therefore, the required accuracy is achieved by selecting and combining optimum optical fiber pieces and adjusting the line length per repeatered section. The accumulated manufacturing errors, caused by the multiple repeaters' spans are compensated at the dispersion adjustment sections that are inserted after each group of ten repeaters' span.

5. System Assembly/Test

The submarine repeaters are manufactured by NEC Yamanashi, Ltd., transported to the submarine cable factory of OCC in Kitakyushu and then connected to the submarine cables to assemble the submarine plant. At this stage, the submarine plant is subjected to a performance test of the following items before loading it on the cable ship. This confirms that the designed performance is optimum.

- Insulation of the power feeding line, voltage drop during power feeding.
- Trace measurement of optical fibers (C-OTDR).
- Wavelength dispersion of optical fibers.
- Gain flatness
- Optical spectrum and optical SNR (Signal to Noise Ratio).

The insertion of gain equalizers and adjustments for dispersion compensation, both described in Section 4, are also performed as a part of this process.

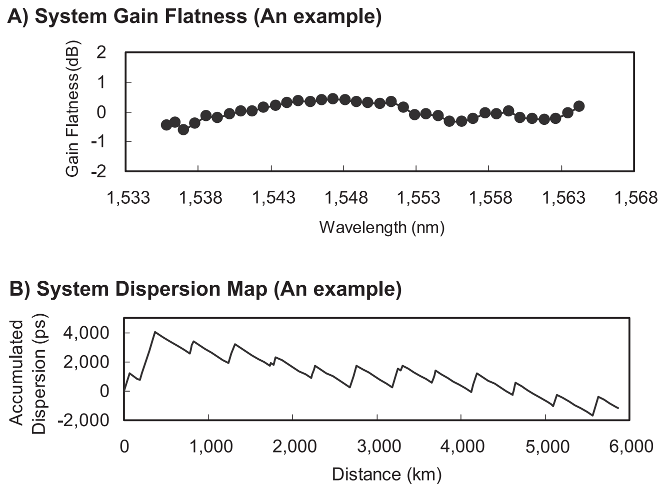

Fig. 5 Examples of the characteristics of a manufactured 5,800-km submarine plant section.

Since the gain flatness of the submarine repeaters varies slightly depending on the repeater temperatures, the system test of an ultra-long distance system with a high accuracy specification is performed by shielding the submarine repeater with a thermostat controlled cover in order to maintain the same temperature as that of the ocean bed.

Fig. 5 shows examples of measurements of the gain flatness and dispersion values of a section of about 5,800 km of an actual 9,000-km system. The measured data indicates that the submarine equipment has been manufactured with extremely high accuracy in accordance with its design specification.

6. System Construction and Commissioning Test

During the laying of the submarine plant using a cable ship, the insulation resistance, voltage drop, optical fiber trace and optical SNR are measured periodically to make sure that it is not being damaged in the laying process.

The installation of the terminal equipment in the landing stations and the laying of the land cable from the beach manholes to the landing stations are performed in parallel with the laying of the submarine plant.

When the submarine plant has been laid, the land cables and the terminal equipment have been connected, system testing on the following items is performed.

- Insulation resistance of submarine plant, voltage drop.
- Optical SNR and Q-value (error rate).
- Monitoring network test (alarm, monitor, etc.).
- Long-term stability (Q-value, alarm).

It is after this system testing that the constructed optical submarine cable system is delivered to the customer.

7. Conclusion

The construction process of submarine cable systems is performed continuously from the beginning of the cable manufacturing, throughout the assembly/testing of the submarine plant, to the loading in the cable ship and the cable laying. Any interruption of this process will cause important effects on the delivery term and costs. It is therefore essential to meticulously plan the specifications of the equipment and cables at the system design stage, as well as for the correction techniques to be applied during the submarine plant assembly. This task should be completed before proceeding to the manufacturing and construction stages. It is the process of design, assembly, construction and testing described above that makes it possible to provide high-quality submarine cable systems in a timely manner. NEC is committed to introducing the latest technologies, while maintaining their present high quality standards. We may thus contribute to the construction of international and domestic submarine networks as a company with a global reputation for competently leading the submarine cable industry.

Authors' Profiles

YONEYAMA Kenichi
Senior Manager
Submarine Network Division
Broadband Networks Operations Unit
NEC Corporation

SAKUYAMA Hiroshi
Senior Manager
Submarine Network Division
Broadband Networks Operations Unit
NEC Corporation

HAGISAWA Akira
Assistant Manager
Submarine Network Division
Broadband Networks Operations Unit
NEC Corporation