Ultra-long Span Repeaterless Transmission System Technologies

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Abstract

The recent increased traffic accompanying the rapid dissemination of broadband communications has been increasing demand for the optical submarine cable systems that form the backbones of international networks. Considering the capability of the repeaterless optical submarine cable system to significantly reduce construction costs compared to the repeatered optical submarine cable system, an increase in the span length of repeaterless submarine cable systems should be regarded as an extremely important research topic.

This paper introduces NEC's long span repeaterless optical cable system technologies, describes the latest repeaterless terminal equipment and puts forward ideas for the direction of future trends.

Keywords

repeaterless transmission system, modulation method, distributed Raman amplification
in-line remotely pumped amplification, 40 Gbps transmission system

1. Introduction

Repeaterless submarine optical cable systems are mainly used in domestic or regional network systems for connections between isolated islands or between the mainland and isolated islands or shore based landing stations. As they do not use optical repeaters in the submarine cables and therefore do not need power feed equipment or a power supply, their construction costs can be much lower than for the repeatered cable systems. This paper introduces NEC's development of the transmission technologies for long span repeaterless optical submarine cable systems, the SLR320SW LTE repeaterless terminal equipment and our proposals for the larger capacity 40 Gbps systems of the future.

2. Configuration of Repeaterless Optical Submarine Cable Systems

Fig. 1 shows the repeaterless optical submarine cable system configuration.

The repeaterless optical submarine cable system comprises a terminal equipment usually installed at the landing station and a submarine optical fiber cable. The terminal equipment consists of the transponder block providing the optical signal transmitter/receiver functions and the WDM (Wavelength Division Multiplexing) block providing the wavelength-division multiplexing/de-multiplexing and dispersion compensation functions.

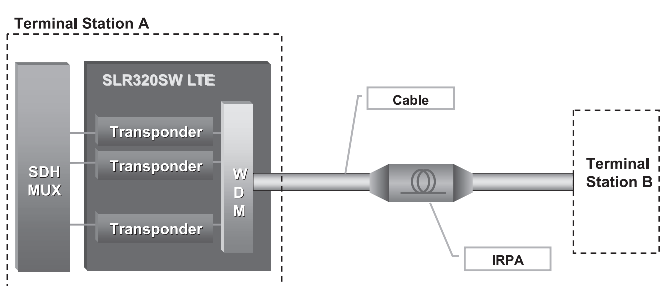


Fig. 1 Repeaterless optical submarine system configuration.

The repeaterless optical fiber cable does not include optical repeaters or power feed equipment for supplying them with power. It is thus able to offer an optical cable system that is streamlined and economical. The receiver characteristics can be improved by means of the IRPA (In-line Remote Pumping Amplifier) technology to be described below. Applying IRPA to a submarine optical fiber cable makes it possible to significantly extend its span length.

3. Key Technologies Supporting Span Length Extension

The repeaterless optical submarine cable systems are designed based on system gain. This is calculated from the difference between the optical level of the main signal sent from the terminal equipment's transmitter to the transmission line's fiber cable and the minimum permissible optical level for the receiving station. In addition, the design also takes into account; the loss of the transmission line's optical fiber, the penalty of the nonlinear optical effect of the fiber that is received during propagation via the optical fiber, the waveform distortion due to wavelength dispersion, cable fault repair work effects and the ageing of the equipment. The technical issues to be solved in extending the span of repeaterless optical submarine cable systems are as follows.

- Increase in the power of the optical main signal incident to the fiber.
- Reduction/avoidance of nonlinear optical effects (self-phase modulation, cross-phase modulation, four-wave mixing and stimulated Brillouin scattering) in the optical fiber transmission line.
- Improvement of the receiving sensitivity.
- Improvement of optical fiber loss characteristics.

The following subsections describe the technologies designed to overcome the above issues.

(1) Suppression of Stimulated Brillouin Scattering

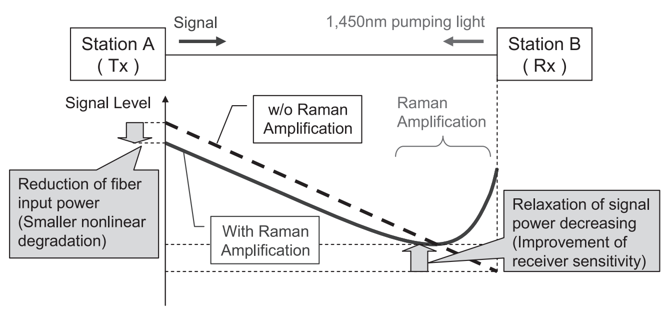
The most effective way for extending the span length of a repeaterless system is to increase its transmission power. However, when the transmission power is increased above a certain threshold, most of the optical signal components above that threshold are reflected toward the transmitting station and the power reaching the receiving station becomes saturated. This phenomenon is called "Stimulated Brillouin Scattering" and its suppression is an essential requirement for repeaterless systems handling high-power signals of more than +10 dBm per wavelength. The effective means for suppression of stimulated Brillouin scattering include expansion of the optical spectrum linewidth of a signal laser and use of a modulation method with a high stimulated Brillouin scattering threshold. For example, expanding the optical spectrum linewidth to around 1 GHz makes it possible to output a high-power signal of greater than about +15 dBm per wavelength to the optical fibers.

(2) Modulation Format

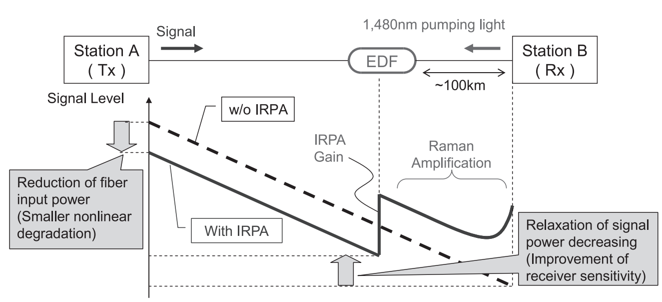
The modulation formats used generally with current optical submarine systems are the On-Off Keying modulations that apply data modulation to the optical intensity, such as the Non Return-to-Zero (NRZ) and Return-to-Zero (RZ) modulations. In addition to these, the Differential Phase Shift Keying (DPSK) modulation method that applies data modulation to the optical phase has recently been attracting attention for its tolerance to the nonlinear optical effect and wavelength dispersion and its effectiveness in improving receiver sensitivity. The RZ-DPSK modulation combining the DPSK and RZ modulations is thus being implemented. Specifically, the RZ-DPSK signal can improve the receiver sensitivity by about 2.5 dB compared to the RZ signal. The RZ-DPSK signal permits a reduction of the optical power to be transmitted to the transmission line fibers. This makes it possible to reduce the nonlinear optical effect that has been a problem with high-power repeaterless transmission, thereby improving the transmission performance of the repeaterless systems.

(3) Distributed Raman Amplification and In-line Remote Pumping Amplification

The effective ways for improving the transmission performance of repeaterless systems without increasing the transmission power are the distributed Raman amplification and IRPA (In-line Remote Pumping Amplification) technologies. **Fig. 2** shows the conceptual diagrams of the optical



(a) Application of distributed Raman amplification



(b) Application of IRPA

Fig. 2 Optical level diagrams of the main signal light in repeaterless systems.

levels of the main signals in the transmission line fibers of repeaterless transmission systems applying distributed Raman amplification and IRPA.

(a) shows a comparison between cases applying and not applying distributed Raman amplification. In the case of distributed Raman amplification, pumping light in the 1,450 nm band is transmitted from the receiving station toward the transmitting station to induce Raman amplification gain in the transmission line's optical fiber and to amplify the main signal light in the 1,550 nm band that is located at about a 100 nm longer wavelength than the pumping light wavelength. The distributed Raman amplification can reduce attenuation of the signal light level at the receiving station. This makes it possible to avoid the nonlinear optical effect accompanying an extreme increase in transmission power and thereby improves the transmission performance.

(b) shows IRPA, with which EDF is installed at a distance of some tens to one hundred kilometers from the receiving station and is pumped by pumping light in the 1,480 nm band from the receiving station in order to amplify the main signal light in the 1,550 nm band. In order to maximize the system gain using this technology, it is important to decide the EDF location by considering the balance between the power at the arrival of the 1,480 nm band pumping light from the receiving station and the power at the EDF arrival of the main signal from the transmitting station. The IRPA is expected to bring about a similar transmission performance improvement effect to the distributed Raman amplification but is regarded as being more effective for increasing the range because its amplification efficiency with reference to the pumping light is higher than that of the distributed Raman amplification.

4. Features of SLR320SW LTE

The SLR320SW LTE is NEC's terminal equipment for use in repeaterless optical submarine cable systems. It achieves a long span repeaterless transmission performance that leads the world by applying the long span transmission technologies described in Section 3 above. The SLR320SW LTE is composed of the SLTM (Submarine Line Terminal Module) that is the transponder block and the WME (Wavelength Multiplexing Equipment) that is the WDM block. **Table** shows the main specifications of the SLR320SW LTE, and **Photo** shows an external view.

Table Main specifications of SLR320SW LTE.

Item	Specifications
Multiplexed wavelengths	Max. 66 wavelengths
Channel spacing	50 GHz, 100 GHz
Wavelength range	1539.4 to 1565.5 nm
Bit-rate	10.709 Gbps 11.096 Gbps (10 GbE)
Modulation format	NRZ, RZ, RZ-DPSK
Optical transmission power	Max. +30 dBm
Remote pumping light source	1,000 mW or more (1,450/1,480 nm bands)
Power Supply voltage	DC -48 V
Operating environmental conditions	Temperature: +5°C to +40°C Humidity: 5% to 85%

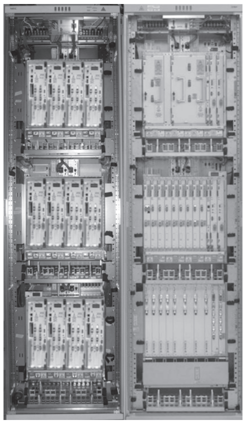


Photo External view of the SLR320SW LTE (Left: SLTM, Right: WME).

(1) SLTM

The SLTM rack accommodates up to twelve 10 Gbps transponder SLTM units.

The line side interface of the SLTM supports the three modulation formats of NRZ, RZ and RZ-DPSK. By applying the concatenated BCH code as the error correction (FEC) code, the high-performance FEC manifests an error correction gain of about 8.5 dB while retaining almost the same redundancy of about 7% as the traditional Reed-Solomon code.

(2) WME

The WME provides the function for a wavelength multiplexing/de-multiplexing of the signal light into up to 66 wavelengths at 50 GHz wavelength intervals. In order to reserve the system gain required for long range repeaterless transmission systems, it also has an optical booster amplification function with a high power of up to +30 dBm. The

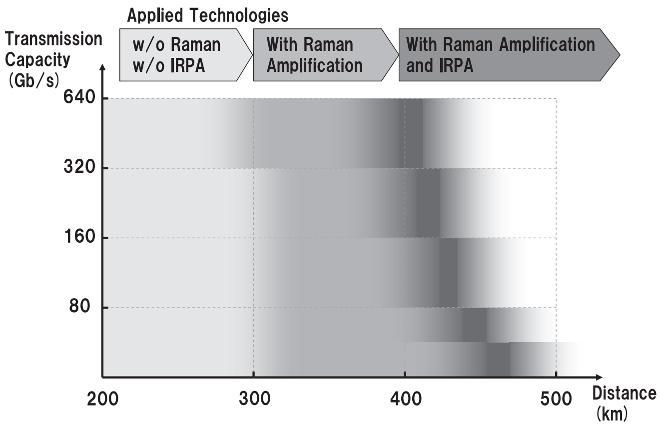


Fig. 3 Application range of SLR320SW.

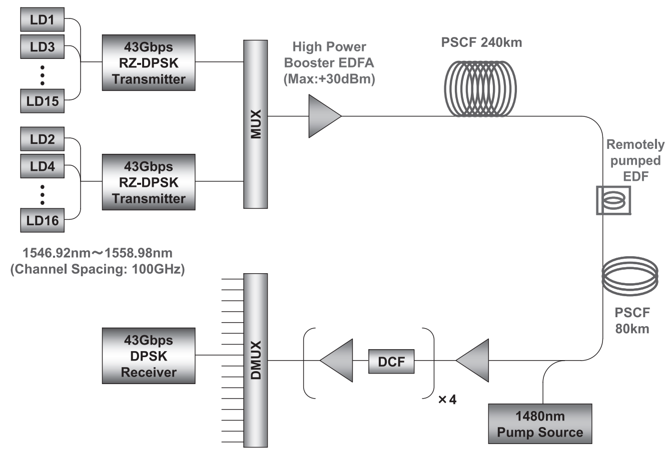


Fig. 4 Configuration of the 40 Gbps repeaterless transmission test bed.

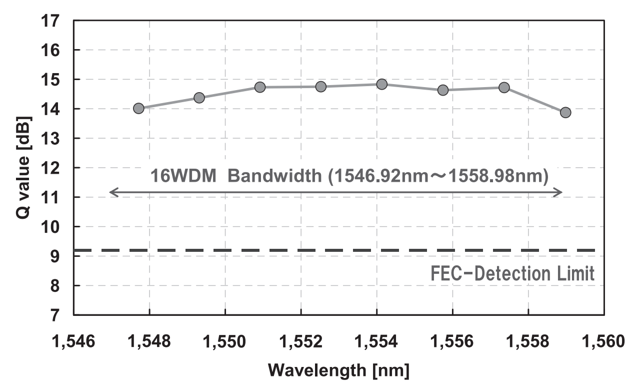


Fig. 5 Results of Q-Value measurements after a 320 km transmission.

receiver performs preamplification for compensating the attenuation of optical signals after fiber transmission as well as compensation for the accumulated dispersion in the fiber. In addition, for use with long span repeaterless systems over 300 km, the WME is equipped with an pumping light source in the 1,450 or 1,480 nm wavelength band with a maximum power of 1,000 mW or more that aims at a significant system gain improvement using distributed Raman amplification and/or IRPA.

(3) Repeaterless System and Its Range of Application

Fig. 3 shows the transmission capacity and applicable distance of the SLR320SW LTE. Although slightly variable depending on the transmission capacity, the applicable distance of an ordinary repeaterless system without distributed Raman amplification or IRPA is about 300 km, that of a system applying distributed Raman amplification is about 400 km, and that of a system applying both distributed Raman amplification and IRPA can be extended to as much as over 400 km.

5. Efforts toward Capacity Increase

Under the requirement for increased transmission capacities and the introduction of 40 Gbps transmission in terrestrial systems, studies into applications of 40 Gbps transmission to repeaterless optical submarine cable systems is undergoing rapid progress. In the following subsections, we will introduce evaluation of a transmission test bed designed to support the practical implementation of the 40 Gbps repeaterless optical submarine cable system.

(1) 40 Gbps-16 WDM-320 km Repeaterless Transmission Test Bed

Fig. 4 shows a 320 km repeaterless transmission evaluation system using 43 Gbps - 16 WDM signals. In the transmitter portion, 43 Gbps RZ-DPSK signals with 16 wavelengths at 100 GHz intervals are used. The WDM signal light is amplified to +29 dBm by the high-power booster EDFA and is then output to the transmission line optical fiber, which is made of pure silica core fiber (PSCF) with a length of 320 km. The EDF for IRPA is installed at the 80 km point from the receiving portion.

The receiver portion has a 1,480 nm light source for use in pumping the IRPA EDF. We evaluated the transmission characteristics by compensating for the dispersion in the WDM signal light after a 320 km transmission and then extracting the measured wavelengths using optical filters and receiving them with the DPSK receiver. After this, we measured the bit error rates of the received signals and evaluated the Q-value which is one of the indices of transmission quality.

(2) Result of the Transmission Characteristic Evaluation

Fig. 5 shows the result of the Q-value evaluation after a 320 km transmission. It shows that the Q-value characteristic may be as high as 13.9 dB or more, even after a 320 km transmission.

This result indicates that the presence of a margin of 4.7 dB is sufficient from the viewpoint of the system design compared to the Q-limit, which is the FEC correction limit of the 40 Gbps transponder, of 9.2 dB. The evaluation above verifies that the capacity increase of a long range repeaterless system of over 300 km by applying the 40 Gbps technology is technically possible.

6. Conclusion

In the above, we introduced the key technologies required for extending the span length of repeaterless submarine cable systems and described the features of the SLR320SW LTE repeaterless submarine terminal equipment. In addition, we also introduced the results of a 40 Gbps - 320 km repeaterless transmission verification as an example of our activities aimed at the application of 40 Gbps transmissions for future capacity increases. We also intend to apply further R&D to the repeaterless submarine cable system transmission technologies that will be aimed at providing products and systems of high quality, performance and reliability to meet the projected requirements for increases in system reach and capacity.

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