EXTREMELY LONG-SPAN NON-REPEATERED SUBMARINE CABLE SYSTEMS AND RELATED TECHNOLOGIES AND EQUIPMENT

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Abstract: This paper describes our line terminal equipment and its key technologies advancements for application to extremely long reach non-repeatered submarine cable systems. The equipment achieves the system gain as high as 85dB for 10Gbps x 16 WDM systems by applying high power remote pumping lights as high as 2000 mW, RZ-DPSK transponder with high receiver sensitivity and optimized system design.

1. INTRODUCTION

The 10 Gbps WDM non-repeatered submarine cable systems have widely been implemented in the last ten years for regional communication networks, such as island to island, mainland to island and coastal festoons. Expansion of non-repeatered link length as well as the capacity is of great importance for further applications because it eliminates the repeaters and power feeding, thus contributes to reduce the system cost compared to the repeatered systems.

This paper describes our submarine line terminal equipment, named SLR320SW, and key technology advancements for application to extremely long reach non-repeatered submarine cable systems. For further capacity increase, the difference between the 10Gbps and 40Gbps non-repeatered systems has been evaluated in terms of the receiver sensitivity and non-linear tolerance.

2. KEY TECHNOLOGIES

In the non-repeatered WDM systems, the high power signal needs to be launched from the transmitter for securing the required OSNR at the receiver. However, the signal degradation due to the non-linear effect limits the transmittable signal power, resulting in limited achievable link length. In this section, key technologies to improve the transmission performance under the limited transmissible signal power are described.

2.1 Distributed Raman Amplification and In-line Remote Pumping Amplification

To overcome this distance limitation, the technologies of distributed Raman amplification and/or In-line Remote Pumping Amplification (IRPA) are effectively utilized to increase transmission distance[1,2].
Distributed Raman amplification can improve received OSNR without extreme increase of the launched signal power from the transmitter due to its distributed gain

property. IRPA technique can also improve the received OSNR by remotely pumping an EDF installed at a distance of some tens to one hundred kilometers from the receiving station. In order to maximize the system gain using this technology, it is important to design the EDF location considering the gain property of EDF and optical level diagram of pumping light source.

Figure 1 shows received OSNR improvement factor by using distributed Raman amplification and IRPA. By increasing the pumping power, OSNR can be improved both for distributed Raman amplification and IRPA. If we apply the pump power source of 1000mW, OSNR improvements for distributed Raman amplification and IRPA are expected to be 8dB and more than 19dB respectively. Furthermore, when we enhance the pumping power from 1000mW to 2000mW, additional 2 to 3dB improvements are expected.

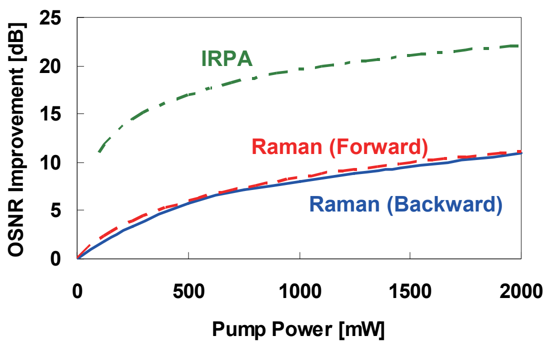

Figure 1: Pump Power vs. OSNR Improvement for Distributed Raman Amplification and IRPA

2.2 RZ-DPSK Modulation

In the non-repeated submarine cable systems, the On-Off Keying modulation, such as the Non Return-to-Zero (NRZ) and Return-to-Zero (RZ) are used generally. In addition to these modulation format, Return-to-Zero Differential Phase Shift Keying (RZ-DPSK) is one of the candidates for further expansion of the transmission distance taking advantage of its improved receiving sensitivity and superior tolerance for nonlinear effect[3]. Figure 2 shows the receiver sensitivities for the 10Gbps signals with NRZ, RZ and RZ-DPSK modulation.

The RZ-DPSK signal achieves the best performance improving the receiver sensitivity by about 2.5 dB compared to the RZ signal. This superior receiver sensitivity with RZ-DPSK signal permits a reduction of the optical signal launch power into the transmission fiber, thereby effectively suppressing the signal degradation due to the fiber non-linearity and improving the transmission performance in the non-repeatered transmission systems.

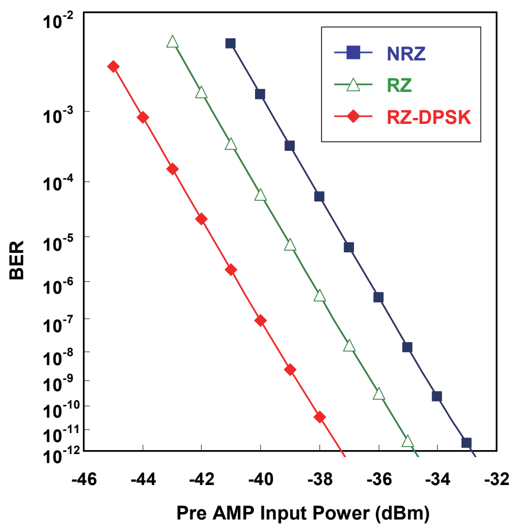

Figure 2: Receiver Sensitivity

3. FEATURES OF SLR320SW LTE

The SLR320SW LTE is our terminal equipment for non-repeated submarine cable systems. It is composed of the Submarine Line Terminal Module (SLTM) which is the transponder block, and the Wavelength Multiplexing Equipment (WME). Table 1 shows the main specifications of the SLR320SW LTE, and Figure 3 shows an external view.

Table 1: Features of SLR320SW LTE

WDM Channels	Max. 66 wavelengths
Channel spacing	50 GHz, 100 GHz
Wavelength range	1539.4-1565.5 nm
Bit-rate	10.709 Gbps 11.096 Gbps (10GbE)
Modulation format	NRZ, RZ, RZ-DPSK
Booster Output Power	Max. +30 dBm
Remote pumping light source	Max. 2000 mW
Power Supply voltage	DC -48 V

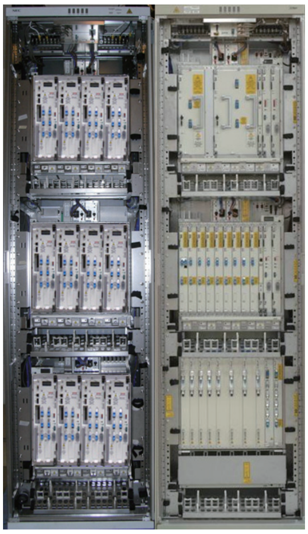

Figure 3: External view of SLR320SW LTE (Left: SLTM, Right: WME)

3.1 SLTM

The SLTM rack accommodates up to twelve 10 Gbps transponder units.
In addition to the conventional NRZ and RZ transponders, the RZ-DPSK transponder [4] is available for superior receiver sensitivity. By applying the concatenated BCH code as the error correction (FEC) code, the high-performance FEC manifests a coding gain of about 8.5 dB while retaining almost the same redundancy of about 7% as the conventional Reed-Solomon code.

3.2 WME

The WME provides the wavelength multiplexing / de-multiplexing function of the optical signals into up to 66 wavelengths at 50 GHz wavelength spacing. In order to achieve the system gain required for long span non-repeatered transmission systems, it also has an optical booster amplification function with a high power of up to +30 dBm. The receiver performs pre-amplification for compensating the attenuation of optical signals after transmission, as well as compensation for the dispersion accumulated in the fiber. In addition, we have newly developed the pumping light source with as high as 2000mW for both distributed Raman amplification and/or IRPA.

3.3 Applicable Range of SLR320SW

Figure 4 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 non-repeated transmission system without distributed Raman amplification or IRPA is approx. 300 km. The transmission distance can be extended to approx. 400km applying distributed Raman amplification, and even more applying both distributed Raman amplification and IRPA. By fully utilizing the combination of distributed Raman amplification, IRPA with high power pumping source and the RZ-DPSK transponder with high receiver sensitivity, a non-repetered system gain as high as 85 dB is achievable for 10Gbps x 16 WDM systems.

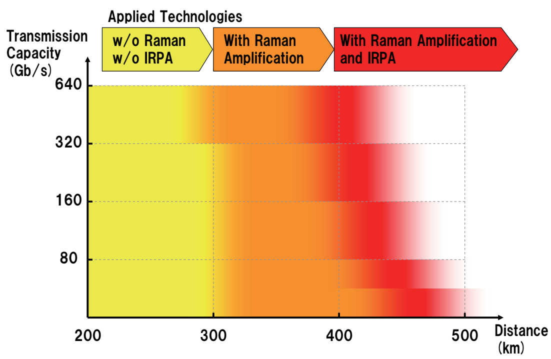

Figure 4: Applicable range of SLT320SW

4. STUDY OF NON-REPEATERED 40GBPS SYSTEMS

40Gbps non-repeatered transmission is of great importance for future capacity increase and the requirement of seamless connection with terrestrial 40Gbps systems. The difference of 10Gbps and 40Gbps non-repeatered systems has been experimentally evaluated mainly in the receiver sensitivity and the non-linear tolerance in order to estimate the transmission performance at 40Gbps.

Figure 5 shows measured receiver sensitivities of 10Gbps and 40Gbps RZ-DPSK signals. The receiver sensitivity of 40Gbps RZ-DPSK signal is inferior to that of 10Gbps by around 6 to 7dB because of the difference of receiver's electrical bandwidth. Figure 6 shows experimental results of power penalties after 320km non-repeatered transmission for the 100GHz spaced 10Gbps RZ-DPSK signal and 100GHz spaced 40Gbps RZ-DPSK signal. In the measurement of 10Gbps RZ-DPSK signal, 6dB additional loss is inserted in the middle of transmission line to equalize the difference of receiver sensitivities between 10Gbps and 40Gbps signals. Q penalty is defined as the difference between the measured Q value and the estimated Q value from received OSNR. From this figure, Q penalties of 10Gbps RZ-DPSK and 40Gbps RZ-DPSK signals are comparable, which indicates that there are no remarkable difference of non-linear tolerances between 10Gbps and 40Gbps signals in non-repeatered transmission, and that the maximum fiber input power of 100GHz spaced 40Gbps WDM signals with RZ-DPSK modulation format can be increased up to almost the same level as that of the 10Gbps.

According to these results, the difference between 10Gbps systems and 40Gbps systems is mainly in the receiver sensitivity and a system gain of around 78 dB is feasible even for 40Gbps x 16WDM systems.

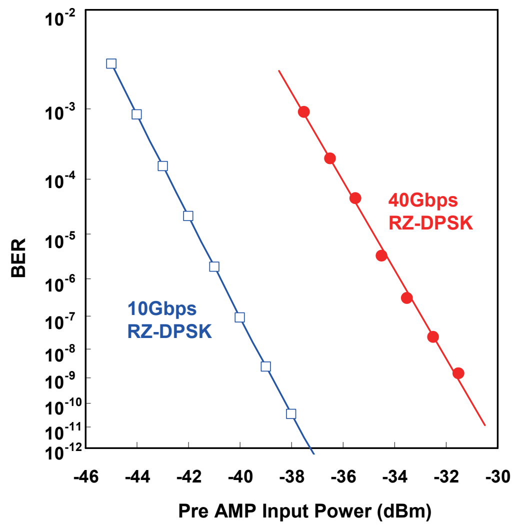

Figure 5: Receiver Sensitivity for 10Gbps and 40Gbps signal

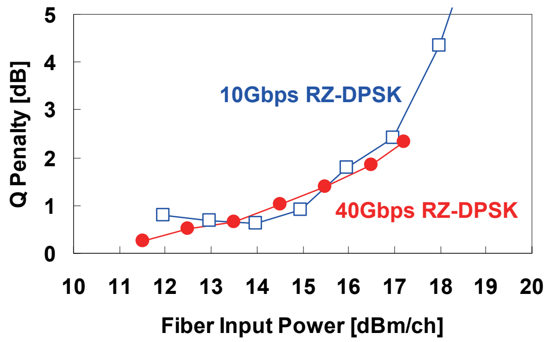

Figure 6: Experimental Q penalty

5. CONCLUSION

Key technologies for long span non-repeatered submarine cable systems and the features of the SLR320SW LTE repeaterless submarine terminal equipment have been presented. It was also confirmed that the difference between the 10Gbps and 40Gbps non-repeatered systems is mainly in the receiver sensitivity.

6. REFERENCES

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