MITIGATION METHOD OF SPECTRUM GAIN DEVIATION IN +D BASED LONG DISTANCE SUBMARINE CABLE SYSTEMS WITH LARGE BANDWIDTH REPEATERS

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Abstract: This paper describes our study result about the impact of Spectrum gain deviation for long-distance submarine cable system. Three mitigation methods for spectrum gain tilt are experimentally compared through D+ fiber-based long distance transmission test-bed with large bandwidth repeaters.

1. INTRODUCTION

Submarine cable capacity has continuously evolved to higher bit-rate signal transmission and number of channel increase. Higher bit-rate signals of 100G has been realized by digital coherent technology [1], higher order modulation and advanced FEC code. WDM channel counts are also increased by extremely large repeater gain bandwidth together with dense WDM technologies. Recently, transmission capacity of more than 10Tb/s per fiber pair has become commercially available for trans-oceanic submarine cable systems.

For such a large capacity submarine cable system, spectrum gain equalization techniques become one of the most important factors to secure the signal quality along the whole spectrum bandwidth.
Furthermore, considering submarine cable system operations, additional gain deviation caused by cable repair works and cable aging needs to be addressed.

In this paper, we study the relationship between spectrum gain deviation and transmission performance for D+ fiber-based long-distance submarine cable system.
To cope with transmission performance variance among WDM channels caused by unavoidable spectrum gain deviation, we also discuss three mitigation methods, level pre-emphasis at the transmitter side, additional GEQ insertion and additional amplifier insertion.

2. SPECTRUM GAIN DEVIATION

Spectrum gain flatness is one of the essential factors for large capacity and long distance submarine cable systems. This is because large spectrum gain deviation causes performance degradation and performance variance among WDM channels by both increased fiber nonlinearity and ASE noise accumulation. [2]
Firstly, WDM spectrum evolution was measured by using D+ fiber-based 9,000 km transmission line for various loss inserted conditions.
Figure 1 shows experimental setup. 9,000km transmission line consists of 60km D+ fiber spans and C-band optical amplifiers with 35nm bandwidth. In order to study the impact on spectrum gain deviation as a function of span loss

increase, an optical attenuator is inserted in every 15 amplifiers (approx. 900km interval with a total of 10 attenuators).

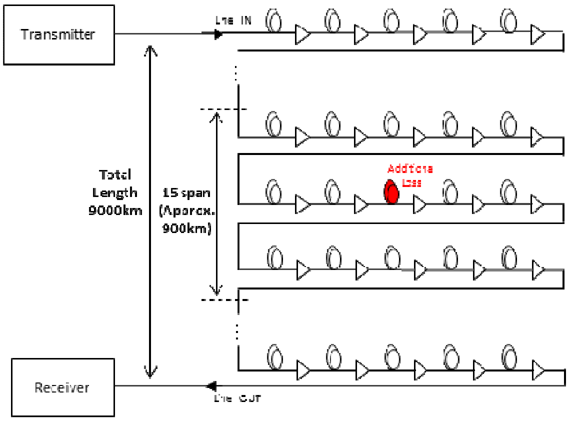
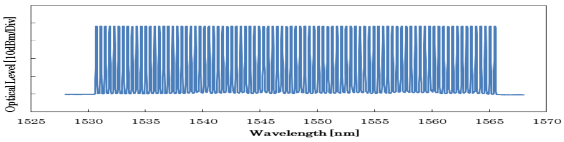


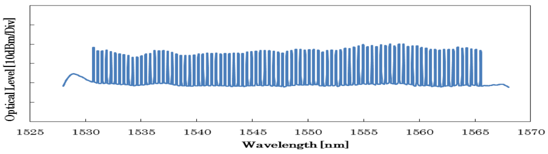
Figure 1: Experimental setup

In this measurement, 88 CW light sources with 50GHz spacing are used.

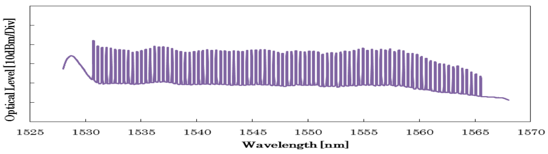
Figure2 shows optical spectrum after 9000km transmission without additional attenuation and with additional optical attenuator of 10 x 5dB.



(a) Before Transmission



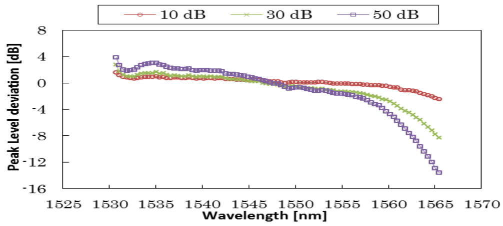
(b) 9000km w/o attenuator



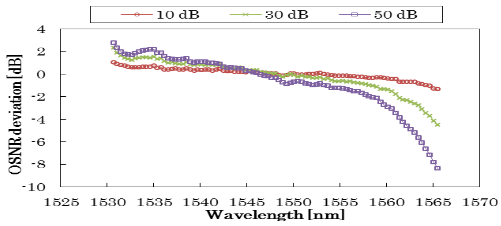
(c) 9000km with 10x5dB attenuator

Figure2: Optical spectrum

Figure 3 shows signal peak level deviation and OSNR deviation after 9000km transmission for three loss inserted cases of 10dB(10x1dB), 30dB(10x3dB) and 50dB(5x10dB). These peak level deviations and OSNR deviations are deviations from the results without loss insertion. As it is clearly seen from this figure, a negative spectrum gain tilt results from the loss insertion which emulates repair work in the cable. Accordingly, OSNR deviations are also observed. Especially, OSNR degradation for longer wavelength is remarkable. After 50 dB loss insertion, peak level difference between shortest wavelength and longest wavelength is as large as 17.5dB and OSNR difference is as large as 11.2dB.



(a) Peak level deviation



(b) OSNR deviation

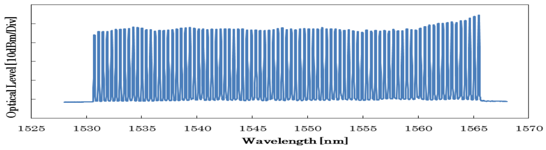
Figure3: Optical spectrum and OSNR after transmission

3. MITIGATION METHODS OF SUPECTRUM GAIN DEVIATION

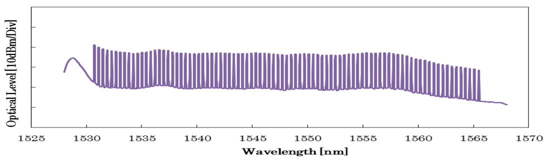
Considering long-term operation during system design life, span loss increase due to cable repair work and cable loss ageing can’t be avoided. So, mitigation methods to cope with spectrum distortion caused by span loss increase are indispensable. Hereinafter, three mitigation methods against spectrum distortion are discussed.

3.1. Level pre-emphasis at the transmitter side

Level pre-emphasis adjustment is well known as one of mitigation methods to equalize the spectrum deviation and transmission performance for WDM channels. Figure 4 shows the optical spectrum at the transmitter side and after 9000km transmission with 50dB loss insertion by applying 10dB level pre-emphasis adjustment insertion. Figure 5 shows peak level and OSNR at 9000km with and without pre-emphasis adjustment. By introducing pre-emphasis adjustment at transmitter side, peak level deviation is reduced from 17.5dB to 12.4dB and OSNR deviation is also reduced from 11.2dB to 5.0dB.

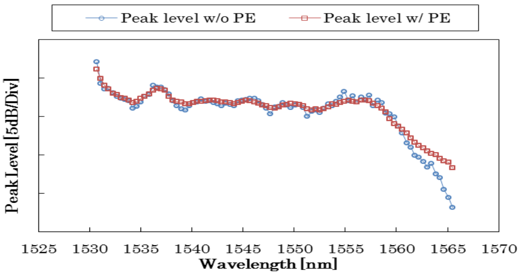


(a) Tx spectrum

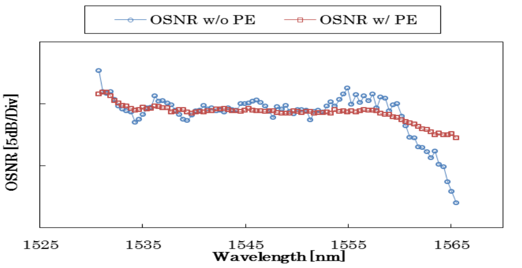


(b) 9,000km

Figure4: Optical spectrum with level pre-emphasis



(a) Peak level



(b) OSNR

Figure5: Optical spectrum and OSNR after transmission (after Tx Pre-emphasis)

Under the 10dB pre-emphasis adjustment condition for 9000km transmission line with 50dB loss insertion, 100G transmission performances are confirmed.

In this measurement, 88 x 100G DP-QPSK WDM signals are used with 50GHz channel spacing. Q values after transmission are measured for three representative wavelengths, 1530.7nm (shortest wavelength), 1548.5nm (center wavelength), and 1565.5nm (longest wavelength).

Figure 6 shows the Q value after 10dB level pre-emphasis adjustment. According to this result, Q value deviation is still observed among 3 measured channels. This performance deviation is mainly caused by extremely large spectrum deviation caused by additional 50dB loss inserted condition. Although performance gaps between channels are mitigated by level pre-adjustment, Q-value degradation is still observed in both edge channels in this extreme case.

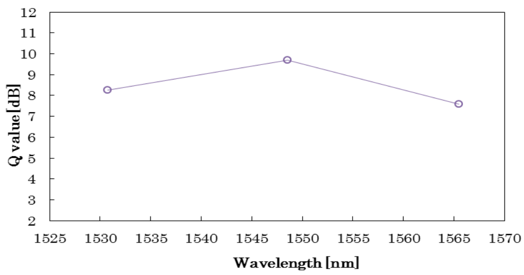


Figure 6: Q value at 9,000km with Tx Pre-emphasis

3.2. Additional Gain Equalizer(GEQ)

One of the effective ways to mitigate the spectrum deviation caused by large amount of span loss increase is to introduce an additional gain equalizer in the line. This method can compensate the spectrum profile deviation in the transmission line. So, effective performance improvement is expected.

We evaluated the effectiveness of the GEQ insertion method by using the same transmission line as shown in figure 1. In this evaluation, three GEQ for 8dBpp negative tilt compensation are located as shown in figure 7.

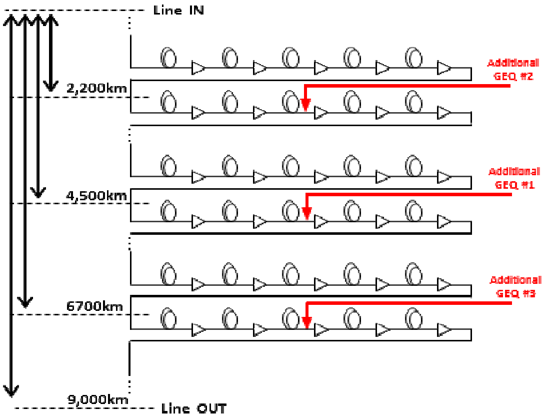


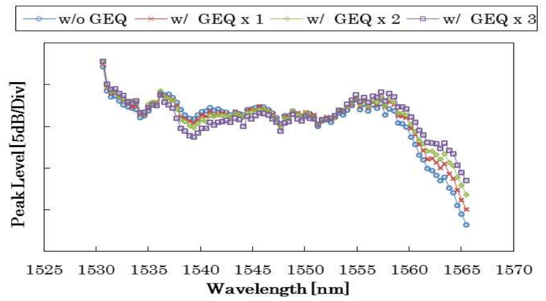
Figure7: Insertion locate of additional GEQ

Figure 8 shows the peak level deviation and OSNR deviation against number of inserted GEQs. The peak level and OSNR are suppressed according to GEQ insertion, especially for longer waveband. After three GEQ insertions, peak level deviation is reduced from 17.5dB to 12.8dB and OSNR deviation is reduced from 11.2dB to 6.4dB.

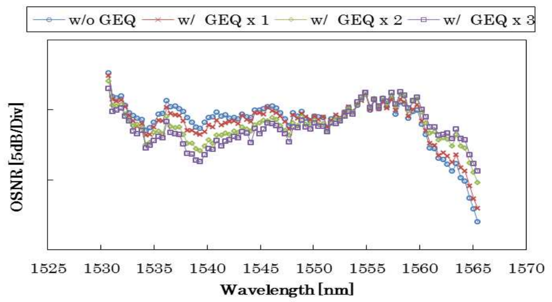
Figure 9 shows Q value measurement result by 100G DP-QPSK signals. For each GEQ insertion condition, level pre-emphasis is also applied.

As shown in this figure, Q value of longer wavelength is improved by additional GEQ and 1.9dB improvement is observed after three GEQ insertions. On the other hand, no improvement is observed for shortest wavelength.

This GEQ device involves not only spectrum equalization characteristics, but inevitable additional insertion loss features. So, this additional GEQ method causes additional span loss increase together with spectrum deviation compensation. This additional loss of GEQ lowers the input power to the following amplifiers, which cause additional negative gain tilt and ASE noise increase especially shorter waveband. As a result, the effectiveness of spectrum tilt compensation by GEQ is limited by the negative tilt generation and the ASE noise generation from the following amplifiers in the short wave-band.



(a) Peak level



(b) OSNR

Figure8: Optical spectrum and OSNR after transmission (with additional GEQ)

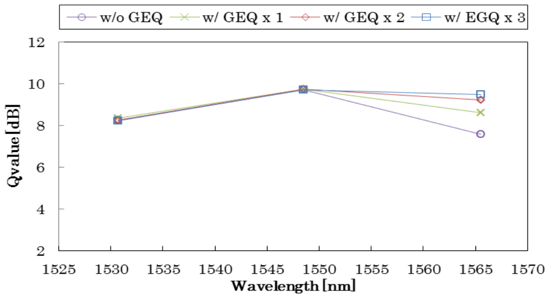


Figure9: Q value at 9,000km with additional GEQ

3.3. Additional amplifier

The insertion of an additional amplifier is another promising candidate for the mitigation of spectrum tilt. The effectiveness of amplifier insertion method is experimentally evaluated. In this evaluation, same transmission test-bed as previous GEQ evaluation is used. Three additional amplifiers are allocated at same positions as additional GEQ evaluation shown in figure 7. The additional GEQs are not used in this section. The amplifier for the spectrum equalization is the same type of amplifier used in transmission line.

Figure 10 shows the peak level and OSNR deviations for each amplifier insertion condition.

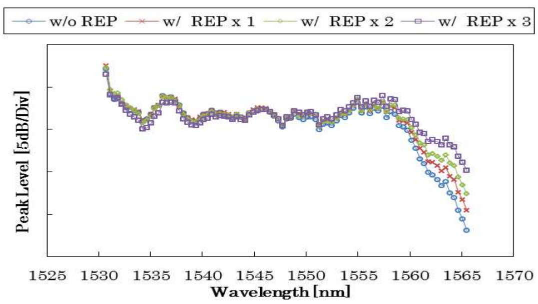
Both the peak level and OSNR deviations are suppressed according to the amplifier insertion. After three amplifier insertions, the peak level deviation is reduced from 17.5dB to 9.7dB and the OSNR deviation is reduced from 11.2dB to 4.6dB.

Figure 11 shows Q value measurement result by 100G DP-QPSK signals. For each amplifier insertion condition, level pre-emphasis is also applied.

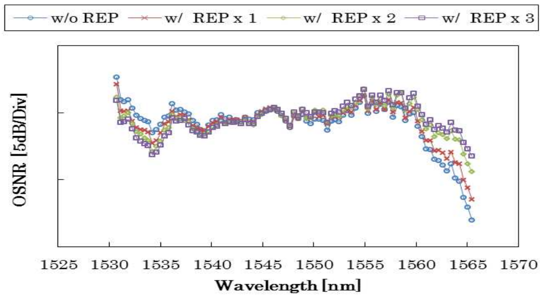
For the additional amplifier method, Q values for both shortest wavelength and longest wavelength are improved according to the number of amplifier increase and comparable Q performances among the three channels are observed after the three amplifier insertions.

Unlike the GEQ method, amplifier method doesn't bring excess loss in the inserted span and effectively generates the positive spectrum tilt without generating excess ASE noise.

So, additional amplifier insertion will considered to promising candidate for spectrum tilt mitigation, if spectrum deviation exceeds the compensation capability of level pre-emphasis adjustment and signal performance drops significantly.



(a) Peak level



(b) OSNR

Figure10: Optical spectrum and OSNR after transmission (with additional amplifier)

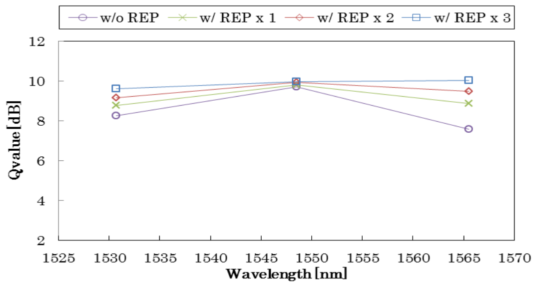


Figure11: Q value at 9000km with additional amplifier

4. CONCLUSION

We have studied the impact of spectrum gain deviation for long distance submarine cable systems. Three mitigation methods for the compensation of spectrum gain deviation are experimentally compared. Additional amplifier insertion can be one of the practical candidates to mitigate the impact of severe spectrum deviation beyond level pre-emphasis adjustment capability.

5. REFERENCES

[1] Lei Xu, et al, "high bit rate multi-level modulation and coding technologies for 100Gb/s submarine DWDM optical communications" SubOptic 2010, paper 202.

[2] Ozan K. and Felton A. "Gain Equalization of EDFA cascades" Journal of lightwave technology, Vol. 15, No. 10, OCTOBER 1997.