DESIGN AND ACCEPTANCE TEST FOR OPEN CABLE SYSTEMS

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Abstract: The open cable system concept has been raised to decouple the wet plant and dry plant of submarine system, in other words, TTE is considered to be independent of wet plant. The main purpose is to adapt the new business model which can take full advantage of TTE technology to rapidly evolve and improve the flexibility of upgrading. The open cable system is built by the wet plant vendors. Conventionally the Q factor is used as a standard for design and acceptance for a traditional turnkey submarine optical transmission system, but the Q factor is dependent on TTE, hence this method is not suitable for open cable system yet. Besides the OSNR, a new parameter-GOSNR (Generalized OSNR) which considers both linear and nonlinear transmission effects, can characterize the open cable system.
This paper will describe the key design and acceptance parameters of the open cable system, and investigate the theoretical design method and acceptance test method of the open cable system. We will present the experimental GOSNR results in several system configurations, such as different channel spacing and different fiber type, and compare the test data with the theoretical calculation results.

1. INTRODUCTION

In recent years, in addition to traditional telecom operators, OTT companies have begun to build their own submarine cable systems, because their data centres distributed around the world require high bandwidth strongly. OTT companies have developed rapidly, dare to use new technologies, and have new requirements for network flexibility and submarine cable system architecture. The open cable concept was first proposed in September 2015, then it began trying to invite public bidding and acceptance for wet plant and dry plant devices separately to match rapid innovation and upgrade of TTE devices. Open cable has gradually become the next research hotspot for vendors and operators. The decoupling of the dry plant and wet plant makes the Q factor for the design and acceptance of the traditional submarine cable system not applicable to the open cable system. In addition to the OSNR, a new parameter GOSNR which considers both linear and nonlinear transmission effects, can characterize the open cable system.

This paper will describe the key design and acceptance parameters of the open cable system, and investigate the theoretical design method and acceptance test method of the open cable system. We will present the experimental GOSNR results in several system configurations, such as different channel spacing and different fiber type, and compare the data with the theoretical calculation results.

2. OPEN CABLE SYSTEM DESIGN

Open cable system mainly includes four design parameters: design OSNR, GOSNR , commissioning OSNR, and Gain Excursion. The design OSNR is the OSNR estimation value considering only the wet plant equipment. The commissioning OSNR defines the acceptance criterion of the system OSNR, containing the average values and the minimum value. It can be obtained by subtracting manufacturing margin and measurement uncertainty from the design OSNR. The gain excursion is an indicator to evaluate the system flatness including the gain tilt and ripple. It is divided into two parts: Positive Gain Excursion and Negative Gain Excursion. In figure1 we show the power spectra at transmitting and receiving ends with the orange line and the blue line, respectively. Both of them are normalized to the RPT output power. The Positive Gain Excursion is the part whose power at the receiving end is greater than that at the transmitting end, and the Negative Gain Excursion is the other. The system flatness indicator needs to comprehensively consider the matching degree of the cable loss spectrum and the RPT gain spectrum, and the design, manufacture, integration and construction capability of the power equalization device. The GOSNR, the key parameter in open cable system, considers the nonlinear noise interference (NLI) as well as the amplified spontaneous (ASE) noise. In a single fiber system, the statistical characteristics of the signal at receiving end can be approximated as a Gaussian distribution and are independent of the ASE noise of the amplifier, and hence the nonlinear noise can be modeled as Gaussian noise P_{NLI}[1].

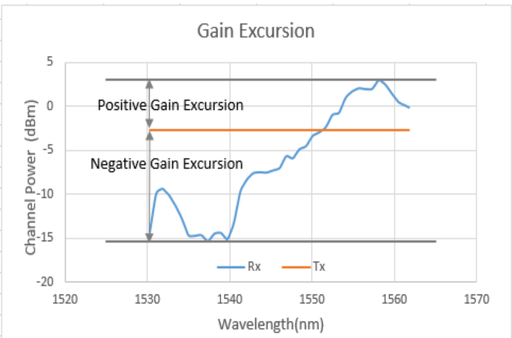

Figure 1: Gain Excursion Schematic Diagram

Among these parameters, the OSNR and the Gain Excursion are original parameters for submarine system, they can be evaluated by traditional algorithm. The GOSNR is a new definition parameter. As a result, the GOSNR needs to be studied comprehensively in open cable system. We describe the GOSNR calculation method and related formula as follows:

$$\mathrm{GOSNR} = \frac{P_S}{P_{ASE}+P_{NLI}} \tag{1}$$

Note: $P_{ASE} = (G * NF - 1)h\nu N_s B_n$

$$P_{NLI} = \int_{B_n} G_{NLI}(f)df$$

The key point in the GOSNR calculation is how to calculate P_{NLI}, where $G_{NLI}(f)$can be calculated using the following formula:

$$G_{NLI}(f) = \frac{16}{27}\gamma^2 \mathrm{L}_{\mathrm{eff}}^2 \cdot \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \mathrm{G}_{\mathrm{WDM}}(f_1) \mathrm{G}_{\mathrm{WDM}}(f_2)\cdot \mathrm{G}_{\mathrm{WDM}}(f_1+f_2-f) \cdot \rho(f_1,f_2,f)\cdot \chi(f_1,f_2,f)df_2 df_1 \tag{2}$$

Note: $\rho(f_1,f_2,f) =$

$$\left|\frac{1-e^{-2\alpha L_S}e^{j4\pi^2\beta_2 L_S(f_1-f)(f_2-f)}}{2\alpha-j4\pi^2\beta_2(f_1-f)(f_2-f)}\right|^2 \cdot L_{eff}^{-2}$$

$$\chi(f_1,f_2,f) = \frac{\sin^2(2N_S\pi^2(f_1-f)(f_2-f)\beta_2 L_S)}{\sin^2(2\pi^2(f_1-f)(f_2-f)\beta_2 L_S)}$$

$\alpha(km^{-1})$: fiber loss coefficient, field calculation value

$\beta_2(ps^2 km^{-1})$: absolute value of dispersion

$\gamma(W^{-1}km^{-1})$: fiber non-linearity coefficient

L_S(km): span length

N_S: number of spans

G and NF: EDFA gain and noise figure

Bn: Noise bandwidth (12.5GHz)

B_{WDM}: Total bandwidth of the signal

L_{eff}: Effective length of the system $L_{eff} = (1-\exp(-2\alpha L_S))/2\alpha$

$L_{eff,\alpha}$: Asymptotic effective length $L_{eff,\alpha} = 1/2\alpha$

For an ideal Nyquist WDM system, an analytical approximation of the average P_{NLI} is given by the following formula [1].

$$P_{NLI} = \int_{B_n} G_{NLI}(f)df \approx B_n \cdot G_{NLI}(0) \qquad (3)$$

Note:

$$G_{NLI}(0) = G_{NLI}^{1span}(0) \cdot N_S^{1+\varepsilon}$$

$$G_{NLI}^{1span}(0) \approx \frac{8}{27}\gamma^2 G_{WDM}^3 L_{eff}^2 \frac{\operatorname{asinh}\left(\frac{\pi^2}{2}\beta_2 L_{eff,a} B_{WDM}^2\right)}{\pi\beta_2 L_{eff,a}}$$

3. OPEN CABLE SYSTEM ACCEPTANCE

The OSNR and Gain excursion acceptance test methods almost follows the original submarine cable system, and the point is to do not use the TTE equipment during the test. Otherwise, the impact of the TTE equipment must be removed. For example, the formula for calculating the impact of the OSNR on the TTE device is as follows:

$$\frac{1}{\mathrm{OSNR}_{WET}} = \frac{1}{\mathrm{OSNR}_{SYS}} - \frac{1}{\mathrm{OSNR}_{TTEASE}} \qquad (4)$$

The OSNR_{WET} is the OSNR of the open cable system which does not contain the TTE equipment. The OSNR_{SYS} is the OSNR of the entire system that includes the TTE and open cable. The OSNR_{TTEASE} is the ASE noise introduced by the amplifiers of TTE equipment. The GOSNR test is complex. According to formula (1), the P_{ASE} can be tested by spectrum analyzer, but the P_{NLI} cannot be directly measured. Therefore, the GOSNR cannot be directly measured using the test instrument. In this case, we need to find a direct measurement index that can reflect the non-linear feature of the system. The linecard Q value after the transmission can reflect the linear and nonlinear overall noise in the system, but it is also affected by the TTE device. For example, the QPSK has the following formula (5),

$$\mathrm{BER} = \frac{erfc\sqrt{\mathrm{SNR}}}{2} = \frac{erfc\sqrt{Q^2/2}}{2} \qquad (5)$$

The equivalent OSNR of receiver can be obtained from the Q-value after transmission and the OSNR sensitivity of the line card used in the Q-measurement, which is represented by iB2B(Q). The diagram below shows the procedure of obtaining the iB2B(Q).

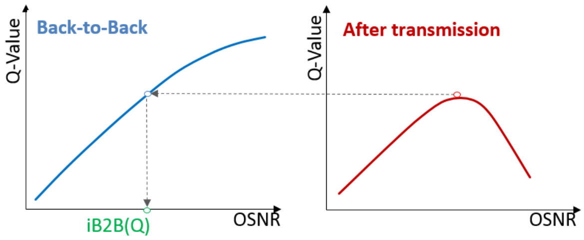

Figure 2: Method of Obtaining iB2B(Q)

After the iB2B(Q) is obtained and the impact of the TTE device is removed, the GOSNR may be obtained, as shown in the following formula:

$$\frac{1}{\mathrm{GOSNR}} = \frac{1}{\mathrm{OSNR}_{WET}} + \frac{1}{\mathrm{OSNR}_{NLI}} = \frac{1}{\mathrm{iB2B(Q)}} - \frac{1}{\mathrm{OSNR}_{TTE}} \qquad (6)$$

In formula (6), OSNR_{TTE} includes the following parts:

$$\frac{1}{\mathrm{OSNR}_{TTE}} = \frac{1}{\mathrm{OSNR}_{TTEASE}} + \frac{1}{\mathrm{OSNR}_{OTHERS}} \qquad (7)$$

In addition to the ASE noise, the TTE equipment responds to factors that are not power dependent, such as the system dispersion, PMD and PDL ect, to affect the Q value. This part is represented by OSNR_{OTHERS}. Then, with reference to formulas (6) and (7), a formula for testing the GOSNR experiment data is obtained:

$$\mathrm{EXP} = \frac{1}{\mathrm{iB2B(Q)}} - \frac{1}{\mathrm{OSNR}_{SYS}} = \frac{1}{\mathrm{OSNR}_{NLI}} + \frac{1}{\mathrm{OSNR}_{OTHERS}} \qquad (8)$$

According to the GN model [1], $P_{NLI} = \eta \cdot P_S^3$, then $\frac{1}{OSNR_{NLI}} \propto P_S^2$ .Here P_S is channel optical power. EXP(P_S) which is a group of experiment data can be obtained by changing the P_S, and $OSNR_{NLI}$ can be obtained by performing linear fitting on EXP(P_S). Then GOSNR is obtained by using formula (6). A typical repeater is a constant output power (or a small range of output power adjustment). Therefore, it is not possible to change the total power to obtain test data but a few channels to be pre-emphasized up and down from the nominal power.

4. EXPERIMENT RESULTS ANALIZIS

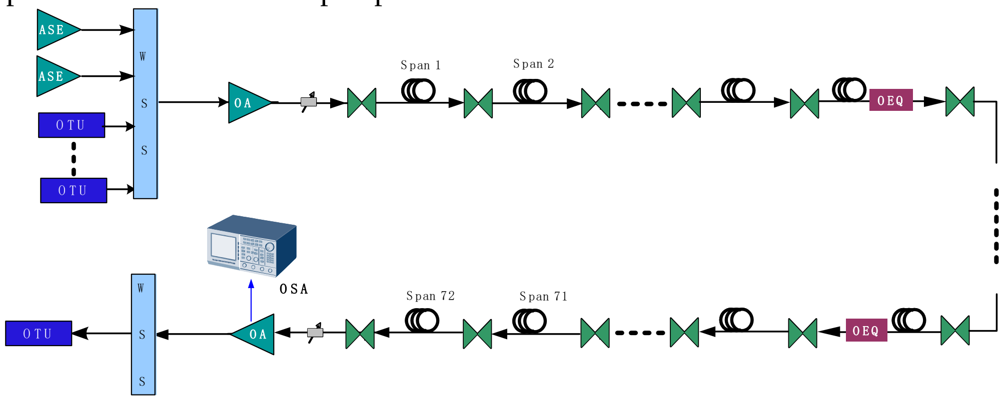

Figure 3: Schematic of the Experimental Setup

TTE line card uses polarization division multiplexed quadrature phase shift keying (PDM-QPSK) code pattern, with 37.5GHz or 50 GHz channel spacing. Two sets of 6000km transmission link systems are established using the 110μm² and 150μm² G654 fiber. The two link both have 73 RPT with 14.5dB gain and 19dBm output power. Figure 3 is the schematic of the experimental setup. The two sets experimental setup are almost the same but fiber type.

We can obtain $OSNR_{OTHERS}$ according to formula (8), and $OSNR_{OTHERS}$ are almost the same with different channel spacing on the 110μm² or 150μm² G654 fiber type link. It reflects that the impaction factors, such as the system dispersion, PMD and PDL ect, to the TTE receiver is not related to the channel spacing. The experimental results, EXP(P_S) are analysed as shown in Figure figure5. In the four scenarios, the experimental data EXP and P_S^2 have a linear relationship.

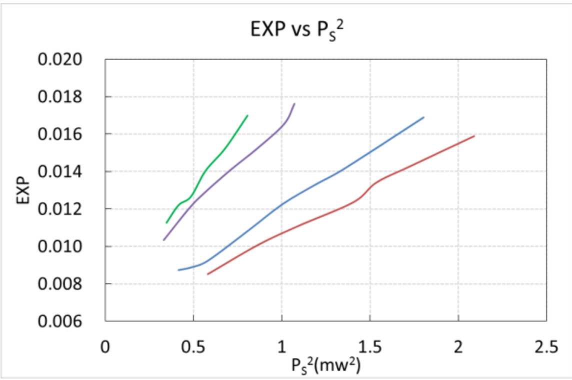

Figure 4: EXP Test Data vs PS2

In figure 4, the vertical coordinate is a linear value of $iB2B(Q)^{-1} - OSNR_{SYS}^{-1}$, and the horizontal coordinate is a linear value of P_S^2, and four data lines showed an obvious linear relationship. The green line is at 37.5GHz channel spacing and the purple line is at 50GHz, and they both are tested on 110μm² fiber system. The blue line is at 37.5GHz channel spacing and the red line is at 50GHz, and they both are tested on 150μm² fiber system.

We can obtain GOSNR from the experimental data according to formula (8), and we can observe the effect of P_S variation on $OSNR_{WET}$ and GOSNR. The test data analyses are shown in Figure 5.

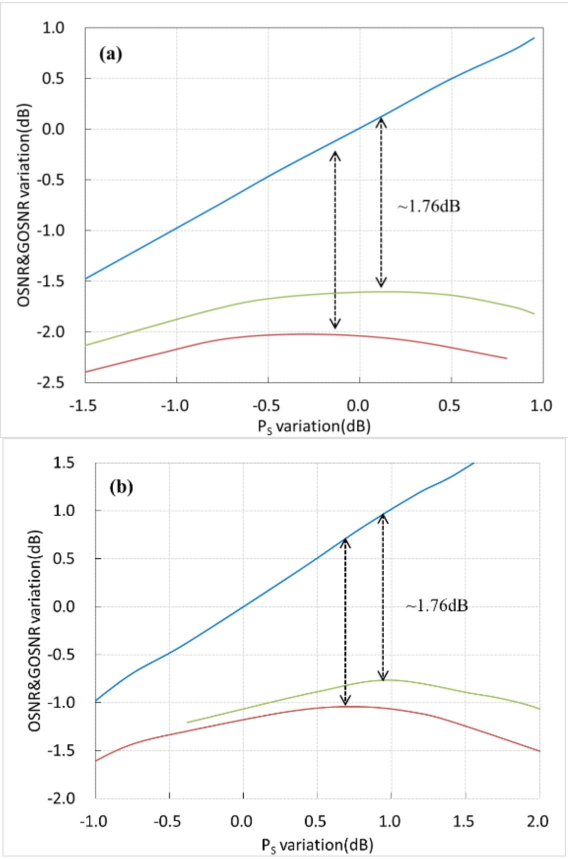

Figure 5: OSNR&GOSNR vs PS

Taking the $OSNR_{WET}$ before pre-emphasis as a reference, observe the change of $OSNR_{WET}$ and GOSNR with P_S. The relation between $OSNR_{WET}$ and channel optical power is independent the channel spacing and fiber type, but GOSNR isn't. Figure 5 (a) is the test results on 110 μm^2 G654B fiber 6000km system, and figure 5 (b) is the test results on 150 μm^2 G654D fiber 6000km system. The blue solid lines are $OSNR_{WET}$, and the red solid lines are the test result at 37.5GHz channel spacing, and the green solid lines are at 50 GHz channel spacing. We can observe that higher channel spacing require higher P_S, and the difference between the maximum value of GOSNR and $OSNR_{WET}$ is about 1.76dB at the best P_S, which complies with the GN model theory [2].

5. THE COMPARISONS BETWEEN TEST AND SIMULATIONS

We compare the theoretical GOSNR with the measured data in a 6000km system using G.654B fiber with channels spaced at 37.5 GHz. Figure 6 shows the comparison of the relative values of GOSNR calculated by simulation and test under the different incident optical power (IOP). The horizontal axis is the IOP, and the vertical axis is the relative value of the GOSNR. The relative value is calculated by subtracting the simulated GOSNR at optimal power point from the simulation and test GOSNR.

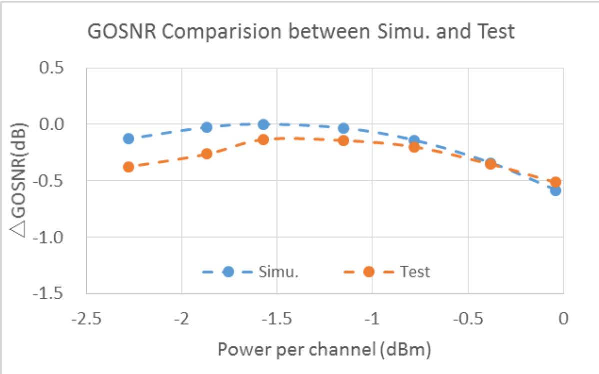

Figure 6: Power vs Δ GOSNR for Test and Simulation

It can be seen that the optimal powers of simulation and test points are basically the same---at -1.6dBm per channel. The GOSNR deviation between the simulation and the test is about 0.15dB at the optimal power point, and the maximum deviation at each IOP is less than 0.25dB. The main reason for the deviation between simulation and test is that the average values of the main parameters of the system, such as RPT gain, NF, fiber dispersion coefficient, and attenuation coefficient, are used in the simulation. However, the parameters of each span in the actual link system may be different. This leads to the difference of the nonlinear cumulative noises between the simulation and test.

6. CONCLUSION

This document describes the key design and acceptance parameters of the open cable system and investigate the theoretical design method and acceptance test method of the open cable system. Based on the nonlinear noise is cubic relationship to incident optical power and $OSNR_{OTHERS}$ is independent of channel optical power, we found the method of removing the impact of the TTE equipment, especially the impact on dispersion, PMD and PDL etc, to test the GOSNR of open cable system. We compare the theoretical and experimental GOSNR data, and they have the same GOSNR level and optimal incident optical power.

7. REFERENCES

[1] P. Poggiolini "The GN Model of Non-Linear Propagation in Uncompensated Coherent Optical System" J. Lightw. Technol., vol. 30, no. 24, pp.3857–3879, Dec. 2012

[2] Edouard Grellier and Alberto Bononi "Quality parameter for coherent transmissions with Gaussian-distributed nonlinear noise", Optics Express, Vol. 19, Issue 13, pp. 12781-12788(2011)

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