SIMPLE INLINE WDM CHANNEL POWER ESTIMATION METHOD BASED ON CROSSTALK SUPPRESSION ALGORITHM IN A SUBMARINE TRANSMISSION LINE

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Abstract: Optical submarine cables play a crucial part as a global communication infrastructure conveying growing data traffic. In order to enhance flexibility on submarine cable communications, branching units with reconfigurable optical add/drop multiplexing (ROADM-BUs) are one of the promising technologies. As the channel allocation is adjusted between trunk and branch fibre pairs according to the traffic demand variation and as channel bandwidth is susceptible to vary depending on the deployed transponders, each power profile in trunk and branch fibres needs to be kept optimized depending on the evolving channel allocation. In this paper, we propose a simple inline WDM channel power estimation method for power profile optimization. The method is based on crosstalk suppression algorithm which enables sufficient accuracy of the channel power estimation. We experimentally verify precision of estimated channel power over a submarine transmission line with the estimation error below 0.43 dB.

1. INTRODUCTION

As a global communication infrastructure, optical submarine cable systems have been widely deployed to accommodate growing data traffic. Optical submarine cables are deployed not only in simple point-to-point configurations between two trunk stations but also connected to multiple landing stations by placing submarine branching units in the submarine cables at the intersection of trunk and branch cables. The traffic demands between multiple landing stations are considered to be difficult to predict over long operating time, typically more than one decade, of the submarine cables. Therefore, branching units with reconfigurable optical add/drop multiplexing (ROADM-BUs) [1] are one of the promising technologies aiming to enhance submarine optical network flexibility.

As the channel allocation is adjusted between trunk and branch fibre pairs according to the traffic demand variation and as channel bandwidth is susceptible to vary depending on the deployed transponders, each power profile in trunk and branch fibres needs to be kept optimized depending on the evolving channel allocation.

Moreover, optical submarine cables have been conventionally installed as full turn-key systems, where both the cables and submarine line terminal equipment (SLTE) were supplied from the same vendor. Recently, discussions on Open Cable [2] have emerged for easier upgrade of their system capacity. In open cable systems, each SLTE is not necessarily supplied from a single vendor but from several different vendors. Consequently, SLTEs from different suppliers coexist in the same cable and are operated with different optical signal parameters, such as symbol rate, modulation format, spectral resources and optical launch power [3]. Depending on the parameters, the optimal input power for each channel is derived by taking into account ASE noise and nonlinear effects [4]. Configured at the optimal launch power increases spectral efficiency of WDM channels and thus network utilization is enhanced [5]. In this case, the conventional static gain equalization scheme is no longer optimal when channel profiles vary and are susceptible to change in the life time of the system. This leads to significant power variations when the signal is amplified successively by numerous optical repeaters. For power profile optimization, channel power monitoring methods as well as adaptive gain control devices are beneficial. OSNR monitoring with AWG filters has been investigated for implementation into repeaters [6] but its resolution is not sufficient to measure inline power variance for DWDM submarine cable systems.

In this paper, we propose a simple inline WDM channel power estimation method using a rough optical bandpass filter, which simplifies its implementation and installation even in wet plant. The method is based on crosstalk suppression algorithm which enables sufficient accuracy of the channel power estimation. We numerically investigate the requirements on monitor devices, concerning filter bandwidth and sampling interval of frequency, for easy implementation. We also experimentally evaluated precision of estimated channel power over a submarine transmission line.

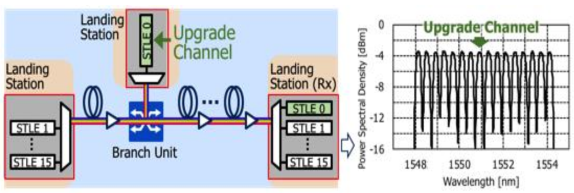

Figure 1: A submarine cable system with a branch unit and the optical spectrum measured at Rx landing station.

2. CONCEPT OF THE SIMPLE INLINE MONITOR

Figure 1 shows typical submarine cable systems and the optical spectrum of WDM channels at the receiver side of landing stations. At the output of the branching unit, power level profile needs to be kept optimized to ensure transmission performance of each WDM channel. For power profile optimization, a ROADM-BU also works as an adaptive gain control device by properly adjusting WSSs. Therefore, channel power monitoring method applicable in branching unit are beneficial for DWDM submarine cable systems with ROADM-BUs. In order to configure the inline optical power profile, we propose a simple optical monitor to measure the inline power variance. The monitor is composed by an OBPF with tuneable centre wavelength, such as temperature variable OBPF, and an optical power meter.

We conducted a numerical simulation to clarify the requirements on the bandwidth (BW) and the interval of spectral sampling points (ΔSamp) of the monitor for three 42.7 Gbaud PM-8QAM optical signals surrounding four 34.2 Gbaud signals. As is depicted in Figure 2, each optical channel is distinguishable if the bandwidth is below 0.2 nm due to power crosstalk between monitored channels.

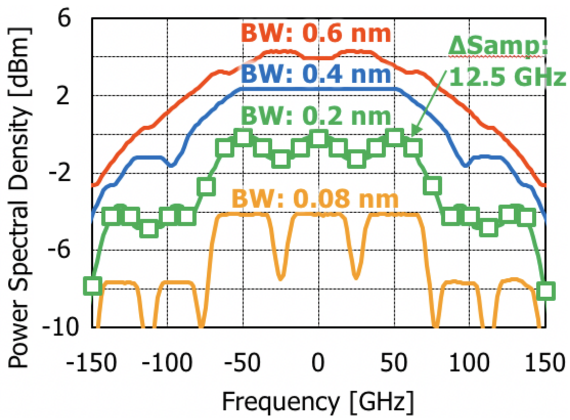

Figure 2: Bandwidth dependency of the simple inline monitor in simulation.

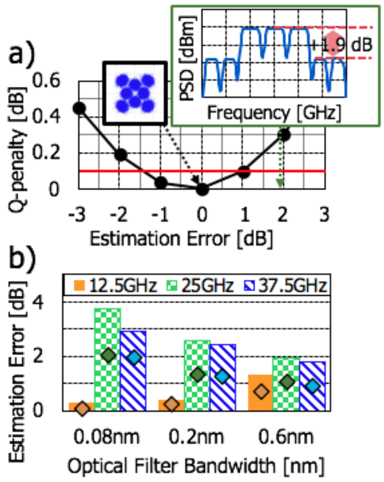

Figure 3: a) Q-penalty over a PSCF link b) estimation error using the simple inline monitor (Point: average, bar: maximum).

For the WDM channels, transmission simulation shows 0.1 dB of Q-penalty arises if estimation error is greater than 1 dB over a PSCF transmission line as is shown in Figure 3 a). Estimation error grows over 1 dB when the interval of spectral sampling exceeds 12.5 GHz as is illustrated in Figure 3 b). These strict requirements have a negative impact on size and cost of the monitor.

3. CROSSTALK SUPPRESSION ALGORITHM

In order to ease the strict requirements, we present a crosstalk suppression algorithm for inline power variance. We model the power crosstalk to the monitoring device as is

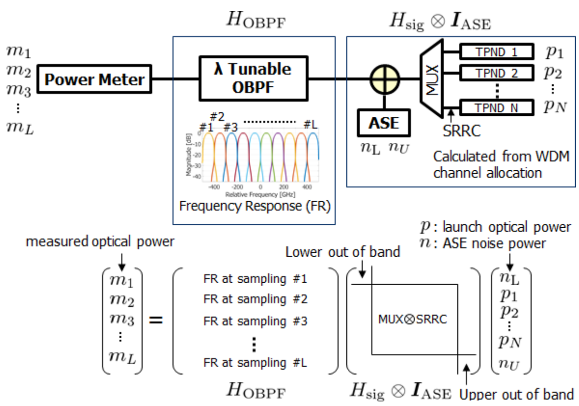

Figure 4: Crosstalk suppression algorithm.

shown in Figure 4. The model consists of optical transponders, an optical multiplexer, ASE noise, a tuneable OBPF and a power meter. In general, the frequency response H_{sig} is calculated from the WDM channel allocation whereas the other frequency response H_{OBPF} is constructed from the measured magnitude of the OBPF. For typical optical communication systems, the OSNR level is high enough and thus the measured power by the power meter is related to the matrix equation in Figure 4. To this end, we estimate the launch power of each channel and ASE noise level by solving the matrix equation numerically. The algorithm is simple enough for implementation in a microprocessor used for hardware control.

Here, we assumed that the transponders generated square root raised cosine (SRRC) shaped signals, a WDM multiplexer and an

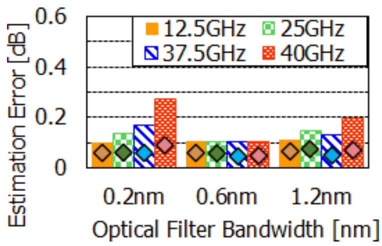

Figure 5: Estimation error with crosstalk suppression algorithm (Point: average, Bar: maximum).

OBPF had ideal squared shapes; OSNR was set as 15 dB / 0.1 nm. Numerical results show that the maximal error was far below 1 dB even for an OBPF of 1.2 nm bandwidth and for an interval of spectral sampling of 40 GHz as is depicted in Figure 5. Therefore, the proposed algorithm supresses the power crosstalk from neighbouring channels and enables to alleviate the requirements on the optical power monitor devices.

4. EXPERIMENTAL SETUP FOR THE DEMONSTRATION

Figure 6 shows the detail of the experimental setup for the demonstration. As a capacity upgrade scenario, a 34.2 Gbaud PM-16QAM optical signal was allocated at 1550.918 nm;

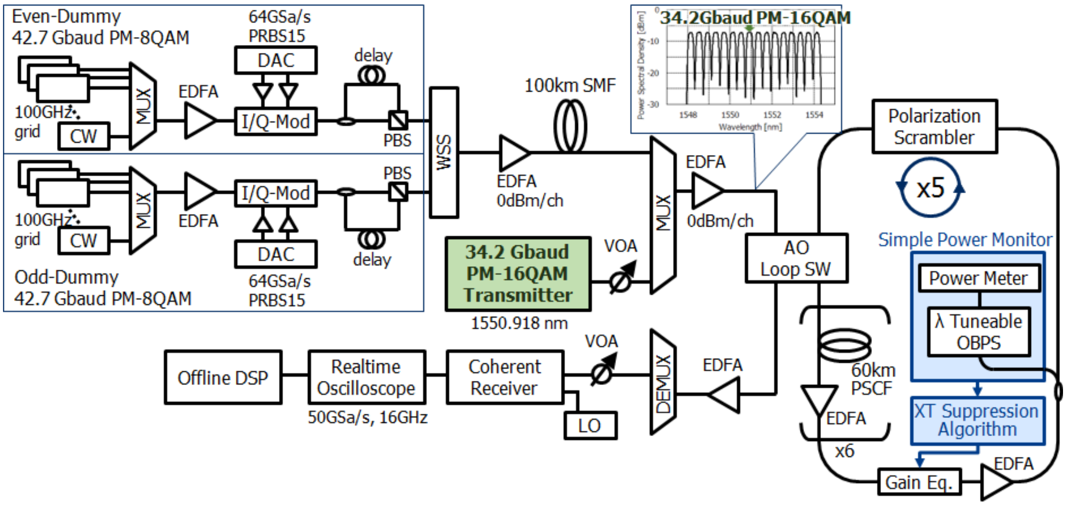

Figure 6: Experimental setup for the demonstration of the proposed simple inline power monitor.

it was inserted in a branching unit manner between fifteen surrounding channels consisting in 42.7 Gbaud PM-8QAM optical signals onto 50 GHz-grid. The surrounding channels were transmitted through a 100km SMF link before being added to emulate the branching configuration. The transmission loop included six spans of 60 km PSCF lines, an adaptive gain equalizer and a polarization scrambler. The signals passed through five loops for a transmission length of 1,800 km. The optimal span input power was at 0 dBm/ch for the surrounding WDM channels; the launch power of an upgrade PM-16QAM signal was set at the same value. At the input of the transmission loop, power

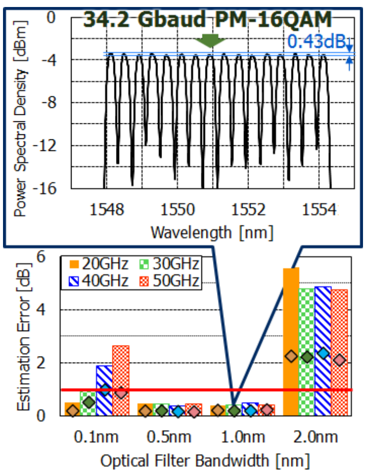

Figure 7: Estimation error (Point: average, Bar: maximum) and optical spectrum with the monitor.

profile of all WDM channels were uniform as is shown in the inset on Figure 6.

5. DEMONSTRATION OF THE INLINE POWER MONITOR

We demonstrated the proposed monitoring method over the PSCF transmission line and we clarified the requirements on the monitoring devices regarding bandwidth and spectral sampling. The H_{OBPF} setting was calibrated according to the measured OBPF characteristics. Using the proposed algorithm, the maximal error satisfied the criteria of below 1 dB when bandwidth was below 1.0 nm and spectral was sampled at finer than 50GHz. However, for the case of bandwidth being 0.1 nm, the estimation error was increased due to imperfect modelling of H_{sig}, whose importance grows relatively for narrow OBPFs. We operated the proposed optical monitor when the maximal error was at the minimum value of 0.43 dB where bandwidth was 1.0 nm and spectral sampling was 30 GHz. Figure 7 illustrates the optical spectrum of the received WDM channels during the operation.

We evaluated the transmission performance on the upgrade channel of a PM-16QAM signal, as is shown in Figure 8. Q-factors were calculated from the measured BER. For the conventional case of uniform launch power of 0 dBm/ch without the proposed inline power monitor nor adjustment of gain equalizer setting after the insertion of the upgrade channel, the Q-factor was 6.5 dB. At the uniform launch power of 0 dBm/ch with the proposed monitor and adjustment of gain equalization setting, 0.1 dB Q-improvement was confirmed, originating from equalization on the gain flatness. Moreover, we investigated launch power dependency on the transmission Q-factor of the upgrade channel. At the optimal launch power of 1 dBm on the upgrade channel, which required our monitor to be maintained on the transmission line, the transmission Q-factor reached 7.1 dB. Therefore, the compensation of inline power variance improves the transmission performance over a submarine cable system even with simple optical monitoring devices and the proposed crosstalk suppression algorithm used to control a tuneable gain flattening filter.

6. CONCLUSION

We have proposed a simple monitor for inline optical power variance among WDM channels using a wavelength tuneable OBPF and an optical power meter. The crosstalk suppression algorithm eased the requirements of the monitor devices regarding the bandwidth of an OBPF up to

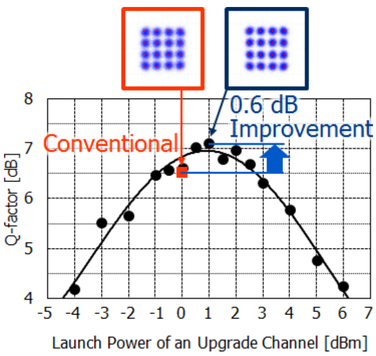

Figure 8: Transmission performance over the PSCF loop.

1.0 nm and the interval of spectral sampling up to 50GHz. We have experimentally demonstrated 0.6 dB improvement of the maximal Q-factor for a 34.2 Gbaud PM-16QAM signal over a PSCF transmission line using the proposed monitor for adaptive gain control to maintain optimal individual channel input power.

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7. REFERENCES

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