Suppression of XPM Penalty in Dispersion Managed Hybrid 10G/40G/100G DWDM Networks Using Group Delay Management

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Abstract *We propose a novel group delay management technique which effectively suppresses XPM accumulation in hybrid 10G/40G/100G DWDM networks. Systematic investigation reveals its high effectiveness for various co-propagating signals, dispersion maps and fiber types.*

Introduction

With increasing demand for transmission capacity network operators would like to upgrade their existing 10Gb/s on-off-keyed (OOK) DWDM networks to 40Gb/s and 100Gb/s. Spectrally efficient quadrature phase shift keying (QPSK)-based modulation formats are considered to be good candidates for 40Gb/s and 100Gb/s upgrade. They show high tolerance to linear impairments such as chromatic dispersion (CD) and polarization mode dispersion. On the other hand, inter-channel non-linear effects such as cross-phase modulation (XPM) can set an ultimate limitation on the transmission reach of QPSK-based signals[1]. Specially designed fiber Bragg grating (FBG) devices were shown to suppress XPM penalties in 10Gb/s networks[2]. Those devices need to be placed within in-line nodes, which make it difficult to upgrade without service interruption. It was also shown previously that XPM penalty could be reduced with proper dispersion map and channel plan[3]. However, it is undesirable to change dispersion map of in-service networks, while channel pre-planning and guard band can reduce system capacity and flexibility in channel plan.

In this paper we propose a novel group delay management (GDM) technique to effectively reduce XPM penalties by introducing additional group delay among channels to induce intentional symbol walk-off without changing dispersion map or wavelength planning. This technique can be easily implemented in-service in existing reconfigurable optical add-drop multiplexing (ROADM) nodes with minimal additional hardware and cost. We also systematically investigate effectiveness of the proposed technique in Hybrid 10G/40G/100G DWDM networks.

Proposed GDM technique and system model

Figure 1 shows a schematic diagram of the proposed configuration. It can be realized using several meters of fibre patch-cord, optical coupler and a spare port of wavelength selective switch (WSS) of ROADM node. In this configuration, channels with different bit rates or modulation formats are routed along two different paths within each ROADM node, where extra delay is applied in one path. Then, the delayed channels are re-combined with the express channels by WSS via one of the add ports.

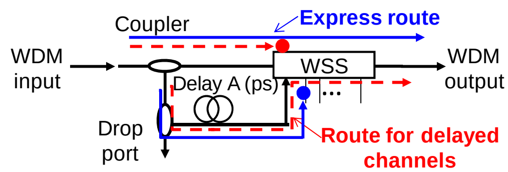

Fig. 1: Proposed ROADM node configuration for group delay management

Figure 2 shows simulation model for 50-GHz spaced five channel DWDM system. In order to investigate XPM suppression from 10Gb/s OOK signals on 40Gb/s and 100Gb/s PSK signals, the center channel was modulated with 10, 20 and 30 GBd RZ-DQPSK signals and the neighboring channels were always modulated with 10GBd NRZ. DWDM signals propagated over 5 spans by 80km NZ-DSF (dispersion coefficient (Dfibre) 4ps/nm/km, effective area (Aeff) 72μm^2) and SMF (Dfibre 16.8ps/nm/km, Aeff 86μm^2) fibre with various in-line CD compensated maps. Delay time *A* for the GDM was introduced at the end of each span to the centre channel whose performance was evaluated.

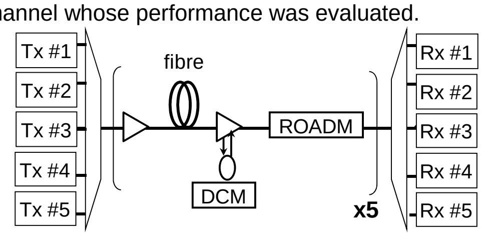

Fig. 2: Simulation model

XPM suppression by group delay management

We started investigation with transmission over NZ-DSF fibre with 0dBm/ch input power and 95% in-line CD compensation. This map, having 15.4ps/nm residual dispersion per span (RDspan) provided 6.2ps walk-off between adjacent channels in each span.

First of all, XPM reduction by the proposed technique was observed by directly measuring XPM phase noise induced by 10Gb/s NRZ signals on a continuous wave (cw) probe. In this case, the centre channel was replaced by cw source and received constellation diagrams were plotted (insets in Fig. 3). The bottom constellation corresponds to the case with proposed delay management (*A*=100ps per node)

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and the top to the case without GDM. Dramatic reduction of XPM-induced phase noise is evident with the proposed GDM configuration although the delay was as small as 100ps.

Next, XPM reduction from co-propagating 10Gb/s NRZ channels on 10, 20 and 30GBd RZ-DQPSK signals as a function of the delay *A* was calculated (Fig. 3), which confirmed the drastic improvement by the introduction of delay management. For example, delay *A* of 75ps per node reduced the Q-penalty from 5.3dB to 1dB for 10GBd RZ-DQPSK signals. Notice that the peak penalty decreases with increase of RZ-DQPSK symbol rate, which is attributed to the relative increase of walk-off with respect to symbol duration.

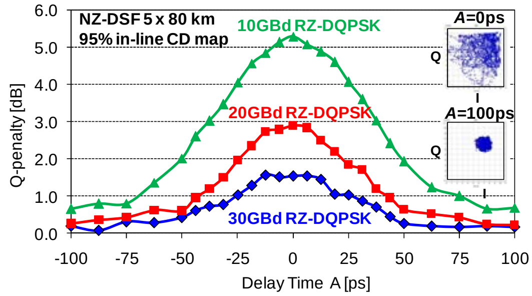

Fig. 3: XPM-induced Q-penalty vs. delay time *A*

Then, we investigated the effectiveness of group delay management for various dispersion maps. Figure 4 shows that with increased amount of RDspan the delay time required to reduce XPM penalties to 1dB slightly increases. This is because larger RDspan leads to larger walk-off between channels, which in turn requires larger amount of delay time *A* to introduce sufficient walk-off to avoid XPM accumulation. For 10GBd RZ-DQPSK, the maximum delay *A* of 125 ps per node would be needed to reduce XPM penalties to 1dB for CD maps with large RDspan. Once again, higher symbol rate RZ-DQPSK signals would need much smaller amounts of delay *A*.

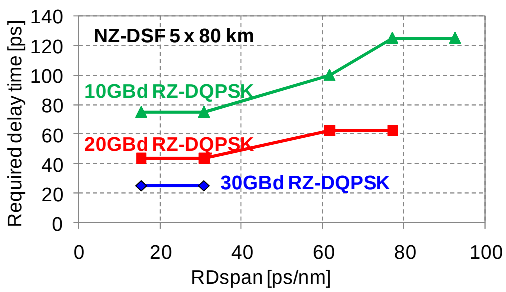

Fig. 4: Required delay time for 1-dB Q-penalty vs. in-line residual dispersion per span

Finally, we investigated XPM suppression for various type of fibres. Fig. 5a corresponds to transmission over NZ-DSF with 80% per span CD compensation, which induces 25ps walk-off. A similar amount of walk-off (27ps) can be generated for SMF with 95% CD map (Fig. 5b). Due to the larger dispersion coefficient in SMF, the walk-off between channels within the nonlinear interaction length is much larger than in NZ-DSF. This significantly reduces the XPM penalty. Therefore, higher launch powers of 4dBm/ch were used to observe XPM penalties similar to those in NZ-DSF.

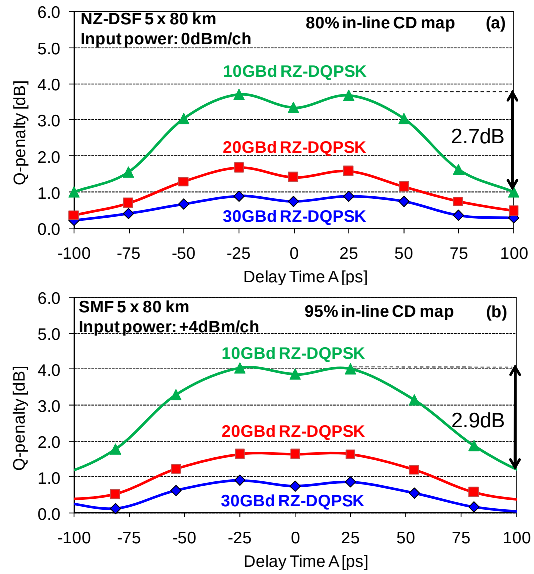

Fig. 5a, b: Q-penalty vs. delay time *A* for (a) NZ-DSF with 80% CD map and (b) SMF with 95% CD map

Discussion

We have shown in Fig. 5 that delay management has similar efficiencies of XPM suppression in SMF and NZ-DSF fibres for the different in-line dispersion compensation maps, but with similar amount of walk-off. Since SMF fibre has a chromatic dispersion coefficient 4.4 times larger than NZ-DSF and a comparable effective area, it benefits from reduced XPM phase noise generation within non-linear length. Thus, it can support 4 dB higher fibre input power for the same amount of walk-off due to CD map.

Conclusions

We proposed and systematically investigated a novel group delay management technique, which can be implemented in-service. We showed that 75ps delay at each node can reduce XPM penalty from 5.2 dB to 1dB for 10GBd RZ-DQPSK signals co-propagating with 10Gb/s NRZ in 5x80km NZDSF fibre with 95% in-line CD map. We also confirmed that maximum required amount of delay time for 1dB Q-penalty for 10GBd RZ-DQPSK is 125ps, which is very easy to implement.

References

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