Dispersion Managed Optical Transmission Links with Optimized Optical Phase Conjugator

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Abstract**—**In this paper, new and simple optical transmission link with fixed dispersion management (DM) scheme, i.e., pre(post) compensation and residual dispersion per span (RDPS) are fixed to net residual dispersion (NRD) = 0 ps/nm, and optical phase conjugator (OPC) having optimal position depending on launch power in WDM transmission system is proposed. Also, effective launch power range of WDM channels resulting 1 dB eye opening penalty (EOP) is induced as a function of OPC position. First, it is confirmed that, for applying DM into WDM transmission link fixed pre(post)compensation and RDPS, which are independence on exact system parameters except launch power, sufficiently are used in WDM links, but OPC with optimal position is needed for effective compensating impairments of WDM channels. And, it is confirmed that effective launch power is broader in case of RDPS = 100 ps/nm than in RDPS = 50 ps/nm. But, it is shown that the best OPC position offset is -0.6 km from a point of view of power window, which is defined as difference between maximum and minimum effective launch power.

Index Terms**—**Dispersion management, Optical phase conjugator, Residual dispersion per span, Net residual dispersion, GVD, Self-phase modulation.

I. INTRODUCTION

The installed standard single mode fibers (SMF) generally have high-chromatic dispersion in the wavelength window around 1,550 nm. From that reason 40 Gbps transmission would be limited to few kilometers in 1,550 nm transmission bandwidth. Thus, compensating techniques of the group velocity dispersion (GVD) will be needed for effective transmission above 40 Gbps [1],[2]. Optical soliton transmission becomes known to a general way to compensate for chromatic dispersion. Because amplifier spacing is required to be shorter than the soliton period for stable transmission and satisfying the conditions for average soliton transmission [3], soliton technique is not effective in these propagation conditions.

Dispersion management (DM) becomes alternative and simple technique of optical soliton for compensating GVD in SMF link. It was reported that high capacity systems in both return-to-zero (RZ) and nonreturn-to-zero (NRZ) signal formats [4] is possible through applying DM into SMF links. In optical transmission systems with DM, if Kerr nonlinearity was not present and input power is sufficient to overcome amplified spontaneous emission (ASE) [2] noise impairment, any bit rate could be transmitted for any distance. Unfortunately the presence of the Kerr effect induces a distortion that accumulates along the link and it is more evident for high bit rates where higher powers are required to ensure a good Signal-to-Noise Ratio (SNR). DM schemes in fiber link have generally 3 types by careful tuning of the amount of GVD as following [5],[6]; first, directly after the transmitter (Tx) (precompensation), second, within the repeaters (in-line compensation), and third, directly before the Rx (postcompensation). The corresponding three quantities, i.e., the amounts of pre(post)compensation, residual dispersion per span (RDPS), and net residual dispersion (NRD), are key parameters for designing a transmission system with high performance.

In order to suppress the nonlinearities mostly by dispersion management, the amounts of GVD compensations of the system should be optimized. This fact makes the design of optical transmission systems, especially WDM transmission, to more complicate.

In NRZ transmission, the dominant effect affecting nonlinear impairment is self-phase modulation (SPM), especially in SMF links. On the other hand, in RZ transmission above 40 Gbps the dominant effects are intrachannel four-wave mixing (IFWM) and intrachannel cross-phase modulation (IXPM) than SPM, FWM, and XPM because the relative pulse intensity will be strong due to narrower pulse width [7].

Optical phase conjugation is one of the effective

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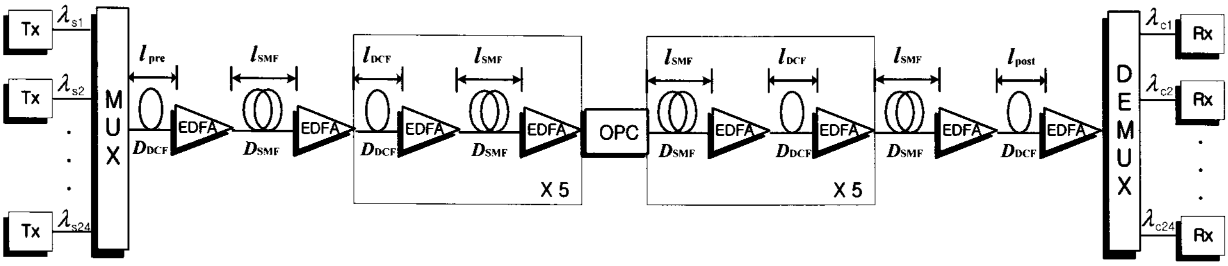


Fig. 1 Configuration of 24 channels × 40 Gbps WDM transmission system.

techniques to reduce GVD and nonlinear impairment mainly due to SPM. The compensation for signal impairment due to GVD and SPM in this technique is theoretically possible through the use of optical phase conjugator (OPC) in the middle of total transmission length. But, the effective suppression of nonlinear impairment is not practically obtained in WDM transmission systems using only OPC, because nonlinearity cancellation by OPC requires a perfectly symmetrical distribution of power and local dispersion with respect to OPC position. Due to the presence of fiber attenuation, this condition cannot be satisfied in real links [8].

In this paper, the simple optical transmission link scheme for reducing GVD and nonlinear impairments only due to SPM in 24 channels × 40 Gbps WDM systems is proposed. The basic transmission link consists of DM and OPC in WDM system with SMF. But, in order to design the simple optical link, first, in DM scheme pre(post) compensation and RDPS are fixed to NRD = 0 ps/nm, and optimal OPC position will be obtained around mid-way of total transmission length. That is, in this paper, the new and simple optical link configuration having fixed DM scheme and OPC of optimized position, which is different link scheme to previous researches [9]-[11], is investigated. Modulation format of WDM channels is assume to be NRZ, because the considered nonlinear impairment is affected only SPM.

II. WDM SYSTEM CONFIGURATION

The configuration of WDM transmission system with OPC is illustrated in Fig. 1. Each transmitter (Tx) of 24 WDM channels is assumed to be distributed feedback laser diode (DFB-LD). The center wavelengths of DFB-LD of channel 1 λ_{s1} and 24 λ_{s24} are assumed to be 1,550 nm and 1,568.4 nm, respectively. The wavelength spacing between each channels is assumed to be 100 GHz (0.8 nm) based on ITU-T recommendation G.694.1. Each DFB-LD are externally modulated by an independent 40 Gbps 128(=2^7) pseudo random bit sequence (PRBS). The modulation format from external optical modulator is assumed to be NRZ. And output electric field of NRZ format is assumed to be second-order super-Gaussian pulse with 10 dB extinction ratio (ER) and chirp-free.

24 WDM channels are multiplexed in multiplexer (MUX) and then transmitted into optical link. Total transmission links consist of 12 fiber span. The nonlinear medium of OPC around mid-way of total transmission length is HNL-DSF. The parameters of OPC using HNL-DSF are as follows; loss of HNL-DSF α_0=0.61 dB/km, nonlinear coefficient of HNL-DSF γ_0=20.4 $W^{-1}km^{-1}$, length of HNL-DSF z_0=0.75 km, zero dispersion wavelength of HNL-DSF λ_0=1,550 nm, dispersion slope $dD_0/d\lambda$=0.032 ps/nm^2/km, pump light power P_p =18.5 dBm, and pump light wavelength λ_p= 1549.75 nm. The 3-dB bandwidth of conversion efficiency η of the OPC is obtained to be 48 nm (1526 ~ 1574 nm). The signal wavelengths are converted to 1,549.5 ~ 1,528.5 nm (these are called to the conjugated wavelength) through OPC. So, allocated 24 signal wavelengths and these conjugated wavelengths are belongs within 3-dB bandwidth of η.

The multiplexed 24 conjugated channels propagated through the rest of half section are demultiplexed and sent into each receiver (Rx) of direct detection. Each Rx consist of the pre-amplifier of EDFA with 5 dB noise figure, the optical filter of 1 nm bandwidth, PIN diode, pulse shaping filter (Butterworth filter) and the decision circuit. The receiver bandwidth is assumed to be 0.65× bit-rate.

III. OPTICAL LINK CONSTRUCTION AND SIMULATION PROCEDURE

Total transmission length is divided into former half section and latter half section with respect to OPC. Each fiber section consists of six SMF spans of length l_{SMF} = 80 km in Fig. 1. SMF as a transmission fiber was characterized by the attenuation coefficient α_{SMF}= 0.2 dB/km, dispersion coefficient D_{SMF}= 17 ps/nm/km, and the nonlinear coefficient γ_{SMF} = 1.41 $W^{-1}km^{-1}$ at

1,550 nm. Thus, accumulated dispersion in one SMF span is 1,360 ps/nm (= 17 ps/nm/km×80 km).

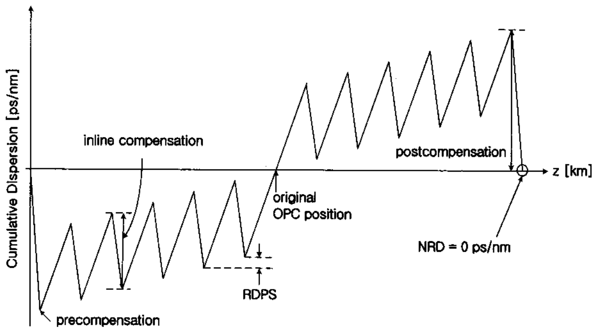


Fig. 2. Dispersion map.

In order to make symmetric distribution of dispersion in dispersion map of Fig. 2 with respect to OPC, dispersion compensating fibers (DCFs) are placed before each SMF link in former half section, on the other hand DCFs are placed after each SMF link in latter half section, as illustrated in Fig. 1. Dispersion coefficient of all DCF D_{DCF} is assumed to be -100 ps/nm/km. When RDPS is determine to be 100 ps/nm in Fig. 2, each length of ten DCF, except first and last DCF, will be 12.6 km, that is, l_{DCF} = 12.6 km in Fig. 1, and simultaneously pre(post)-compensation must be -1,860 ps/nm in order to set NRD is to be 0 ps/nm. Thus, in this case, both first and last DCF length have to be 18.6 km, i.e., $l_{pre} = l_{post}$ = 18.6 km in Fig. 1. Also, if RDPS is determined to 50 ps/nm in Fig. 2, l_{DCF} will be 13.1 km and $l_{pre} = l_{post}$ = 16.1 km in Fig. 1.

Under the condition of DM scheme of NRD = 0 ps/nm above mentioned, optimal OPC position, which depend on launch power of WDM channels, will be investigated.

IV. SIMULATION RESULTS AND DISCUSSION

Fig. 3 illustrates EOPs of best channel and worst channel, which are resulting best performance and worst performance among 24 channels, respectively, and EOP difference between these two channels as a function of OPC position offset (displacement of exact OPC position from middle of total transmission length), when launch power of each channel is 3 dBm. It is shown that optimal OPC position resulting minimum EOP difference is presented at -0.2 km OPC position offset.

The result of Fig. 3 means that system performance of each channel is varied by changing OPC position but the small deviation from that in mid-way is caused by applying DM scheme into SMF links. It is expected that optimal OPC position minimizing EOP difference depends on launch power of channels because SPM effect dominantly depends on optical power. Thus, it is necessary to obtain optimal OPC position as a function of channel launch power in order to investigate the effect of launch power on optimal OPC position in fixed DM scheme.

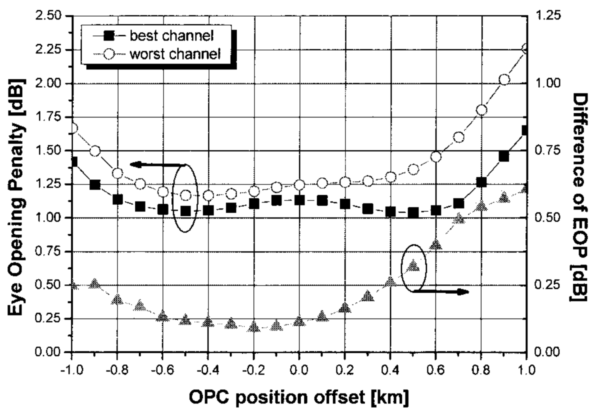


Fig. 3. EOP and EOP difference as a function of the OPC position offset.

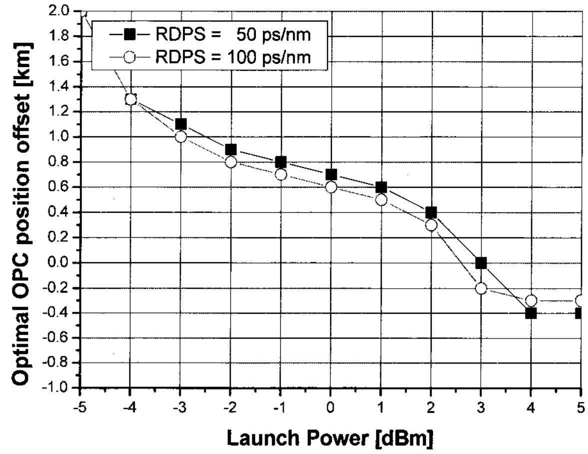
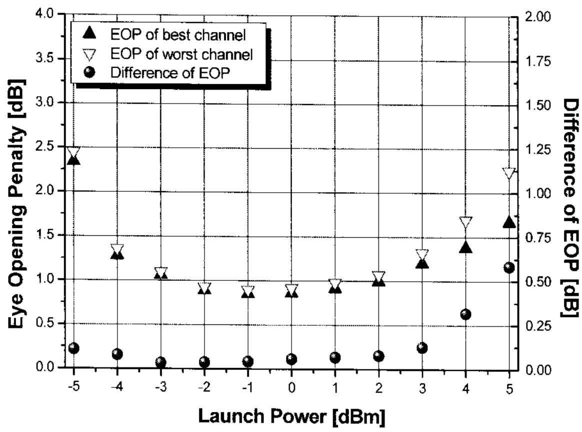
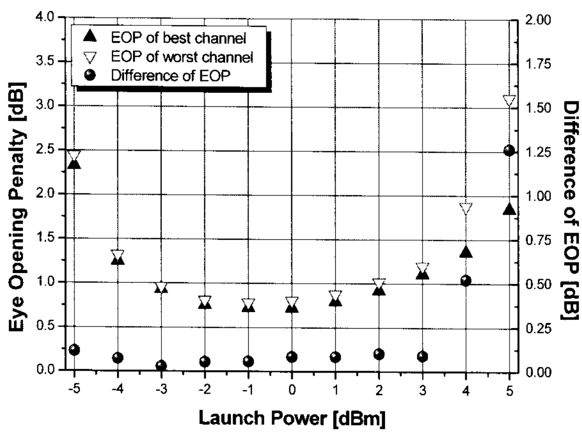


Fig. 4. Optimal OPC position offset versus launch power of WDM channels.

Fig. 4 shows optimal OPC position offset as a function of channel launch power, these values are obtained by determining the minimum EOP difference in each launch power transmission. It is shown that optimal OPC position largely depends on channel launching power and optimal OPC position offset in 50 ps/nm RDPS is slightly larger than that in 100 ps/nm RDPS. Optimal OPC position has to closer to Tx as channel launch power is more increased in both case of 50 ps/nm and 100 ps/nm RDPS. But, in the case of below 3 dBm launch power, optimal OPC position offset of each launch power has positive values, that is, OPC position must shift to Rx. This result means that the effective compensation is achieved by increasing total accumulated dispersion in former half section than that in latter half section below 3 dBm launch power. This result is caused by following reason; the relative low peak power of optical pulse due to the relative large dispersion in former half section fall down nonlinearity of WDM pulses before OPC, thus compensation effect in OPC exactly is enlarged.



(a) 50 ps/nm RDPS



(b) 100 ps/nm RDPS

Fig. 5. EOP and EOP difference as a function of launch power of WDM channels.

Fig. 5 illustrates EOPs of best channel and worst channel and EOP difference between these two values at optimal OPC position of each launch power obtained in Fig. 4. For example, in Fig. 5(a), three data plotted at 0 dBm launch power show values of EOPs and EOP difference obtained at +0.7 km OPC position offset as a result of Fig. 4. If 1 dB EOP is permitted as a reception performance criterion of worst channel, in 50 ps/nm and 100 ps/nm RDPS effective launch power include -2 dBm to +1 dBm, and -3 dBm to +2 dBm, respectively.

The results obtained from Fig. 4 and Fig. 5 mean that it is difficult to decide the commonly optimal OPC position, which is independence on WDM channel launching power in fixed DM scheme. Thus, for usefulness of results obtained this research, it is necessary to induce design rule concern with launch power and OPC position in order to design optical transmission link for high-speed WDM systems.

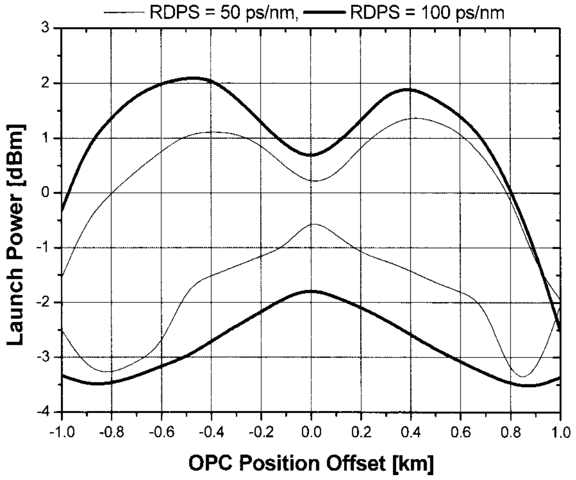


Fig. 6. OPC position offset versus effective launch power.

Fig. 6 illustrates effective launch power of WDM channel, which means launch power resulting 1 dB EOP of worst channel, as a function of OPC position offset. It is shown that effective launch power range is broader in the case of OPC position offset than non-offset (i.e. OPC position offset is 0 km) in both case of 50 ps/nm and 100 ps/nm RDPS. This means that changing OPC position in fixed DM schemed WDM systems is more effective.

Power window is defined as difference between maximum and minimum effective launch power. It is confirmed that the best OPC position offset is -0.6 km, because power window is obtained to be 3.55 dB and 5.16 dB in 50 ps/nm and 100 ps/nm RDPS, respectively.

V. CONCLUSION

This paper discussed simple optical transmission link with fixed DM scheme and OPC having optimal position depending on launch power in WDM transmission system. It was confirmed that, for applying DM into WDM transmission link with fixed pre(post)compensation and RDPS, DM techniques are independence on exact system parameters except launch power and are sufficiently used in SMF-based links, but OPC with optimal position is needed for effective compensating impairments of WDM channels.

It was shown that optimal OPC position has to be closer to transmitter as channel launch power is more increased. And, effective launch power of WDM channel, which means launch power resulting 1 dB EOP of worst channel, is broader in the case of OPC position offset than non-offset. It was also confirmed that the best OPC position offset is -0.6 km from a point of view of power window.

It is expected that the results obtained in this paper will contribute to design the simple WDM transmission links, because fixed DM scheme in this paper is based on system with NRD = 0 ps/nm.

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