Article

MSSI-based Dispersion-managed Link Configured by Randomly-distributed RDPS Only in Former Half Section

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Abstract: The weakness of the dispersion-managed link combined with optical phase conjugation to compensate for optical signal distortion caused by chromatic dispersion and nonlinear Kerr effect of standard single mode fiber is its limited structural flexibility. We propose dispersion map that can simultaneously compensate for the distorted wavelength division multiplexed signal while increasing the configurational flexibility. Each residual dispersion per span (RDPS) in the former half of the proposed link is randomly determined, and in the latter half, the arrangement order of RDPS is the same as or inverted in the former half. We confirm that the dispersion maps in which the RDPS distribution pattern in the latter half is opposite to the arrangement order in the former half are more effective in compensation, and rather, the compensation effect is better than in the dispersion map of the conventional scheme. The notable result of this paper is that the increase of flexibility can be achieved through random arrangement of RDPS in the former half, and the compensation improvement can be achieved by through inverse arrangement in the latter half which make the distribution profile of each half link roughly symmetric with respect to the midway optical phase conjugator.

Keywords: dispersion management; mid-span spectral inversion; dispersion map; optical phase conjugator; residual dispersion per span; random distribution; chromatic dispersion; nonlinear Kerr effect; wavelength division multiplexed

1. Introduction

In optical link consisted of standard single mode fiber (SSMF), chromatic dispersion and nonlinear Kerr effect are the significantly intrinsic barrier to increasing transmission distance and bit-rate. Optical phase conjugation has proved to be an efficient technique to compensate the signal impairment due to both phenomena. Principally, optical phase conjugator (OPC) places in the middle of total transmission length, this scheme is refer to as mid-span spectral inversion (MSSI). In this system, the entire signal distorted through former half of total link preceding the midway OPC is phase conjugated. The dispersive and nonlinear Kerr effect of the phase-conjugated signal are reversed through latter half of total link, and finally the deteriorated signal can be recovered, if the dispersion-power profile is symmetric with respect to the OPC position [1,2]. The symmetry of dispersion-power profile is difficult to establish in real link, because of loss of fibers and amplification of signal power by erbium-doped fiber amplifiers (EDFAs) in a lumped amplification system [3].

Several approaches to maximize the symmetry in MSSI have been proposed. Among of them, applying short span length into transmission link was contribute to increase the symmetry [2], however, this increases the required number of EDFAs, consequently, nonlinear Kerr effect is more increased as optical signal power increase. Other approaches include the use of distributed Raman amplification [4,5] and applying MSSI into dispersion-managed link [6,7]. Another limitation of optical phase conjugation in real link is the difficulty of implementing flexible link configuration. That is, the transmission link parameters, such as the length of SSMF, dispersion accumulated in each span, and more importantly OPC position have to be determined to symmetrize the local dispersion distribution and power profile with respect to OPC. For this reason, OPC position should be fixed around midway of total link, the length of each SSMF should be generally constant, and maximum launch power of signal will be restricted. Thus, the variety of link configuration is limited in optical phase conjugation system for compensation of chromatic dispersion and nonlinear Kerr effect.

Dispersion management (DM) is well-known approach can mitigate fiber chromatic dispersion [8–11]. Dispersion coefficient of the dispersion-compensating fiber (DCF) is opposite to SSMF, thus, the dispersion accumulated in SSMF can be eliminated or reduced by controlling the length and coefficient of DCF. In DM link, if Kerr nonlinearity was not present and input power is sufficient to overcome amplified spontaneous emission (ASE) [12] noise impairment, any bit rate could be transmitted for any distance.

In DM link configuration, the significant link parameter capable to impact the dispersion compensation is residual dispersion per span (RDPS), which is defined as dispersion accumulated in each fiber span. The RDPS is determined by the lengths and dispersion coefficients of SSMF and DCF. The simplest configuration in DM link is that the same RDPS is applying into each fiber span of whole link. This configuration means the lengths and coefficients of fibers are fixed to uniform values in every spans. However, this uniform distribution of RDPSs also restrict to adaptive implement DM link on demand of network design plan.

One approach to supplement the incomplete compensation by the difficulty of symmetry in MSSI is the combination of DM link configuration [6,7]. Authors have also confirmed the compensation improvement of 960 Gb/s wavelength division multiplexed (WDM) transmission in MSSI-based DM link [13–15]. In our researches related with the applying MSSI into DM link, the various DM configurations have been proposed by using non-uniform RDPSs, such as artificial distribution of arbitrary RDPSs, random distribution of various RDPSs, and asymmetric dispersion map with respect to midway OPC, to expand flexibility of link configuration. On the flexibility front, the best scheme is random distribution, i.e., RDPSs with different magnitude are freely allocated for each fiber span, with no intention of deployment. However, the random distribution of RDPSs results in unsatisfactory compensation, since it is difficult to make symmetry of dispersion-power profile with respect to midway OPC. From a viewpoint of performance, on the other hand, the best compensation is achieved by the artificial distribution and the predetermined RDPSs; especially, the gradually ascending or descending distribution of these RDPSs in each half link and the resulting overall dispersion profile of each half is maintained to symmetric with respect to midway OPC.

From analysis of our previous researches, it is confirmed that there is a conflict of interest between the conditions of link parameters for flexibility and for compensation effect. That is, it is difficult to achieve simultaneously two aims of flexibility and the best compensation through the established attempts using RDPSs distributions. Therefore, it is needed to investigate another way to increase the compensation performance and to extend the flexibility. One of the easier approach should be compromise method, i.e., the selective mix of various distributions of RDPSs for each half link.

In this study, we numerically demonstrate the compensation of 960 Gb/s wavelength division multiplexed (WDM) signal in MSSI-based DM link, in which RDPSs of only former half link are randomly distributed and RDPSs of rest half link are artificially distributed. The deployment of RDPSs in latter half link are as followed two kinds; RDPSs in latter half link are reverse or followed with those in former half link. We also assess the compensation performance in DM link configured by all-randomly distributed RDPSs in both halves for comparison with proposed schemes.

2. Dispersion-managed Link and WDM System Modelling

2.1. Dispersion-managed link

The dispersion-managed link with the embedded midway OPC for transmitting WDM 24-channels of 40 Gb/s is illustrated in Figure 1. Each half link comprises 27 fiber spans, thus total link consists of 54 fiber spans. All fiber spans include SSMF and DCF, and the length of SSMF is fixed to 80 km. The previous researches have shown that the deployment of fibers in a fiber spans affects the compensation of the distorted each channel [13]-[15]. The compensation is more increased when the arrangement of SSMF and DCF is to be symmetric with respect to OPC, that is, the arrangement order of two fibers in fiber span is different with each half link. In this paper, DCF precedes SSMF in every fiber spans of former half link; DCF, on the other hand, is placed after SSMF in latter half link.

In this study, the RDPS of fiber span will be randomly decided to one among 27 values from -1,300 ps/nm to 1,300 ps/nm, which are distinguished with interval of 100 ps/nm. Each RDPS is determined by the length of DCF, because the length of SSMF, and dispersion coefficients of SSMF and DCF are fixed. We assume SSMF parameters as follows: the dispersion coefficient is 17 ps/nm/km, the attenuation coefficient is 0.2 dB/km, and the nonlinear coefficient is 1.41 $W^{-1}km^{-1}$. And DCF is characterized as follows: dispersion coefficient is -100 ps/nm/km, the attenuation coefficient is 0.6 dB/km, and the nonlinear coefficient is 5.06 $W^{-1}km^{-1}$. These parameter values are assumed for wavelength of 1,550 nm.

The completed random distribution of RDPSs means the arrangement order of random-valued RDPS is not fixed in both halves. However, as mentioned earlier, the MSSI-based DM link configured with completed random distribution is not sufficiently compensating for the distorted WDM channels, because it is difficult to establish the symmetry of local dispersion with respect to OPC. Therefore, in this work, the RDPS distribution in former half link is only essentially random, while the distribution in latter half link is taken account of two cases with artificially arranged RDPSs as follows. First, the case is expressed as "random-inverse," in which the RDPS of each fiber span in former half link is randomly and independently determined as one of 27 values, while the arrangement of RDPSs for each fiber span in latter half is opposite to that of former half. Second, in the latter half, the arrangement of the RDPSs of the fiber span is the same as the randomly aligned RDPSs in the former half, this case is called "random-follow". We also consider "all-random" distribution, in which RDPS of each fiber span is simultaneously random-arranged in both halves, to compare the compensation performance.

In considering three cases, we investigate the different 50 distribution patterns. However, for a reasonable analysis of the compensation performance, the RDPS arrangement of the former half link is made to be the same in all three cases. In summary, after randomly deciding the arrangement of 27 RDPSs for each fiber span of former half, RDPS for each fiber span in latter half is allocated in the same order (random-follow distribution), and in the reverse order (random-inverse distribution) as the arrangement in former half. Dispersion-managed links with completely different random arrangement of RDPS in the former half and latter half are also considered. These processes are independently repeated 50 times.

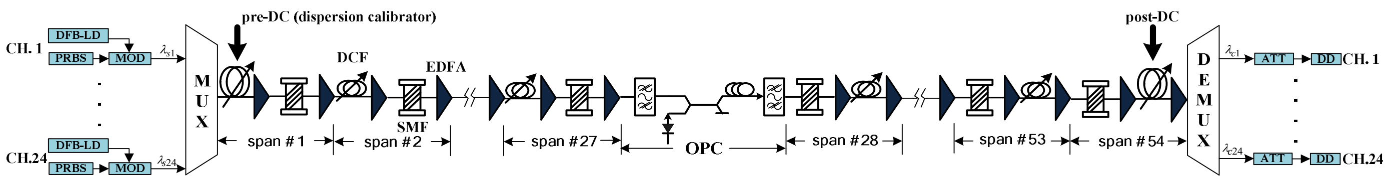

Figure 1. The 960 Gbps WDM transmission system through the dispersion-managed link and the midway OPC.

It is well known that the best compensation occurs, when the net residual dispersion (NRD) should be sustained near 0 ps/nm rather than 0 ps/ nm in "pseudo-linear" systems such as the proposed this system [16]. This feature means that certain fiber span must take the role in maintain the above-mentioned condition. The first fiber span and the last span as certain fiber span for this role, which are called the pre-dispersion calibrator (DC) and post-DC, respectively. However, in this research, only pre-DC plays the role of an NRD controller of total link by varying its own length; that is, the DCF length of the first fiber span will be varied for deciding the NRD of former half link, and simultaneously, the DCF length of the last fiber span should be fixed to make the NRD of latter half link 0 ps/nm.

2.2. WDM transmitters, recivers and midway OPC

The transmission part of each WDM channel consist of pseudo-random bit sequence (PRBS) for data generation, distributed feedback laser diode (DFB-LD) for light source, and external modulator. First, an independent 40 Gb/s 127 (=2^7-1) PRBS is generated and then intensity-modulating the light emitted by DFB-LD in external modulator. Following ITU-T recommendation G.694.1, the center wavelength of each DFB-LD is assumed to be from 1,550 nm to 1,568.4 nm with 100 GHz (0.8 nm) interval. The output of modulator is assumed to be return-to-zero (RZ) pulses. The output electric field of the RZ format is assumed to be a second-order super-Gaussian pulse with a 10-dB extinction ratio (ER), duty cycle of 0.5, and chirp-free.

The RZ pulses of 24 channels are multiplexed in a multiplexer (MUX) and propagated through the former half of the dispersion-managed link. However, the propagated signals are deteriorated by the chromatic dispersion and Kerr nonlinearities. The distorted optical signals are phase-conjugated in the midway OPC through the four-wave mixing (FWM) process of the input waves and the pump light. Highly nonlinear dispersion-shifted fiber (HNL-DSF) is selected as a nonlinear medium for phase conjugation. The power and wavelength of the pump light for generating the phase-conjugated waves are assumed to be 18.5 dBm and 1,549.75 nm, respectively. Consequently, each wavelength of the conjugated 24 channels in the midway OPC is then arranged from 1,549.5 nm to1,528.5 nm (-0.8 nm interval).

The conjugated WDM signals are propagated through the rest half of total link and then demultiplexed. We assume that each receiver follows the direct detection method. The receiver bandwidth is assumed to be 0.65 times 40 Gb/s. The WDM receiver is comprised of EDFA with noise figure of 5 dB, optical filter, PIN diode as photodetector, pulse-shaping Butterworth filter, and decision circuit.

3. Numerical Assessment

The nonlinear Schrödinger equation (NLSE) of Eq. (1) is only known as the expression for the propagation of the optical signal in the silica fiber such as SSMF and DCF [17].

$$\frac{\partial A_j}{\partial z} = -\frac{\alpha}{2}A_j - \frac{i}{2}\beta_{2j}\frac{\partial^2 A_j}{\partial T^2} + \frac{1}{6}\beta_{3j}\frac{\partial^3 A_j}{\partial T^3} + i\gamma_j\left|A_j\right|^2 A_j + 2i\gamma_j|A_k|^2 A_j, \quad (1)$$

In Eq. (1), j, k = 1, 2, …, 24 ($j≠k$), A_j represents the complex amplitude of the optical signal of the j-th channel, z is the propagation distance, β_{2j} is the group velocity dispersion (GVD), β_{3j} is dispersion slope, γ_j is nonlinear coefficient, and $T = t - z/v_j$ is the time measured in a retarded frame. The last two terms of (1) express the effect of nonlinearity including self-phase modulation (SPM) and cross-phase modulation (XPM). The XPM has little impact on the system performance because of the high dispersion coefficient of the standard SSMF and, hence, its high walk-off [18]. The XPM effect on dense WDM signals is also omitted. The most common approach for solving (1) is the split-step Fourier method [17].

$$EOP\ [dB] = 10\ log_{10}\frac{EO_{rec}}{EO_{btb}}, \quad (2)$$

We use eye opening penalty (EOP) and timing jitter of the received optical signal as the assessment factor. The EOP is expressed by Eq. (2), where EO_{rec} and EO_{btb} are the eye

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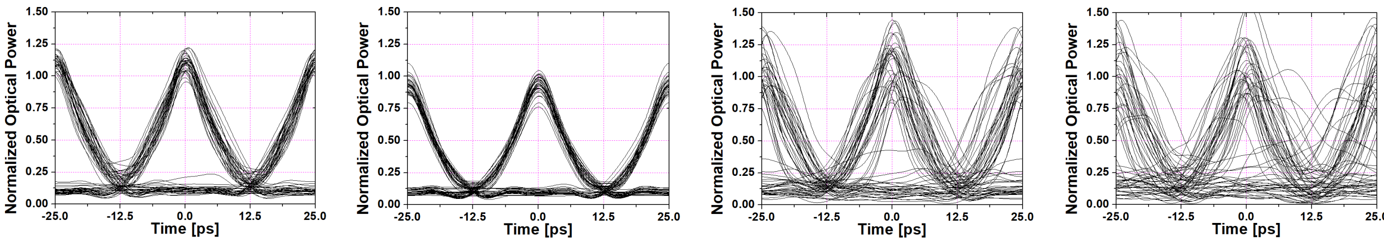
opening of receiving optical signals and the back-to-back optical signals (i.e., the reference signals), respectively. The eye opening is defined as twice the averaged power of all of the received signals divided by the smallest power level of the 'one' optical signal minus the largest power level of the 'zero' optical signal.

The compensation performance criterion is 1-dB EOP, which is equivalent to the pulse broadening (the ratio of root mean square (RMS) width of the received pulse to RMS width of the initial pulse) of 1.25 and corresponds to a bit error rate (BER) of 10^{-12} [19]. We also use 2.5 ps, which is one tenth of duration of 40 Gb/s, as a performance criterion for timing jitter.

4. Simulation Results and Discussion

Figure 2 shows the eye diagrams of the worst channel launched with 5 dBm power into dispersion-managed link configured by the three random cases and the conventional scheme. The conventional scheme of Figure 2(a) corresponds to the case where the RDPS of all fiber spans is uniformly distributed by 0 ps/nm. For comparison, the results of Figure 2(b) to Figure 2(d) are obtained by making the RDPS arrangement order of each fiber span in the former half the same as below: 1100 ps/nm, 900 ps/nm, -600 ps/nm, 800 ps/nm, 1200 ps/nm, -1000 ps/nm, -400 ps/nm, 300 ps/nm, 100 ps/nm, -900 ps/nm, 0 ps/nm, -100 ps/nm, -500 ps/nm, -1200 ps/nm, -1300 ps/nm, -1100 ps/nm, -700 ps/nm, 400 ps/nm, 700 ps/nm, 1300 ps/nm, -300 ps/nm, 600 ps/nm, 1000 ps/nm, -200 ps/nm, 200 ps/nm, 500 ps/nm, and -800 ps/nm.

By comparing Figure 2(b) to Figure 2(d), it can be seen that the reception quality is excellent in the dispersion-managed link with the random-inverse distribution shown in Fig. 2(b). Rather, the compensation result in this case is more improved than the conventional scheme of Figure 2(a). It is judged that this result appears because it has OPC in the middle of the transmission path. In other words, it can be expected that the compensation of distorted channels through MSSI increases as the dispersion distribution becomes more symmetric around the midway OPC, and random-inverse corresponds to the distribution close to the symmetry.

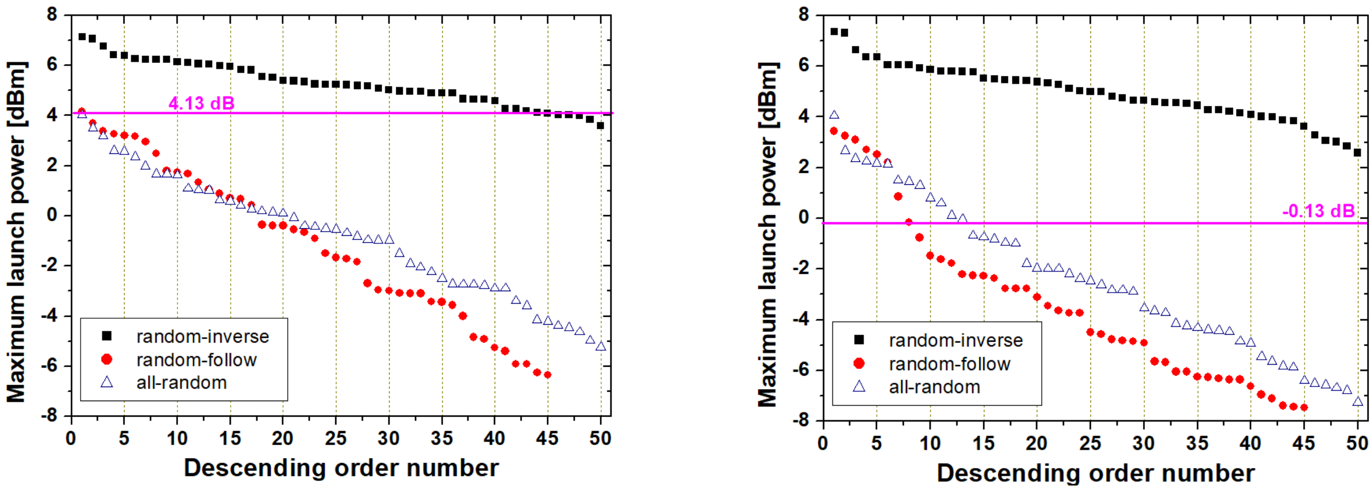


(a) (b) (c) (d)

Figure 2. The eye diagrams. (a) conventional scheme, (b) random-inverse distribution, (c) random-follow distribution and (d) all-random distribution.

In the conventional scheme, the maximum launch power values that produce 1-dB EOP and 2.5 ps of timing jitter are obtained 4.13 dBm and -0.13 dBm, respectively. Figures 3(a) and 3(b) show the maximum launch power values corresponding to 1-dB EOP and 2.5 ps timing jitter, respectively. In Figures 3(a) and 3(b), "descending order number" means that the resulting maximum launch power is sorted from the largest value to the smallest value, in order to facilitate comparative analysis.

First, it can be seen from the result of Figure 3(a) that EOP characteristics in the rest of the random-inverse distribution are superior to that of conventional scheme except for three cases. In particular, in timing jitter analysis, it can be confirmed from Figure 3(b) that the compensation characteristics in all 50 random-inverse distributions are superior to that of the conventional scheme. An interesting fact that can be found in Figures 3(a) and 3(b) is that the compensation characteristics in the all-random distribution are generally better than those in the random-follow. This result can be judged that among the 50 random patterns of RDPS, the number of cases of making the dispersion distribution close to symmetric with respect to the midway OPC is more in all-random distribution than in random-follow distribution. In contrast, the random-follow distribution deviates from symmetry a lot because the dispersion map of the latter half is the same as that of the former half.



(a) (b)

Figure 3. The maximum launch power of the worst channel. (a) resulting 1-dB EOP is, and (b) resulting 2.5 ps timing jitter.

In Figure 3, "descending order number" is used for convenience of comparison, but all of three random distribution cases are performed 50 times with different random arrays. And, the pattern numbers are assigned in the order in which simulations were performed. Figure 4 compares pattern number 48 with the largest difference in performance between EOP and timing jitter and pattern number 49 with the smallest difference in random-inverse distribution. It can be seen from Figure 4 that, depending on the random distribution pattern of RDPS, the variation of timing jitter is larger than that of EOP. This can be confirmed in Figure 4, where the difference in the launch power, which produces 2.5 ps timing jitter, is larger than the difference in launch power that produces 1-dB EOP.

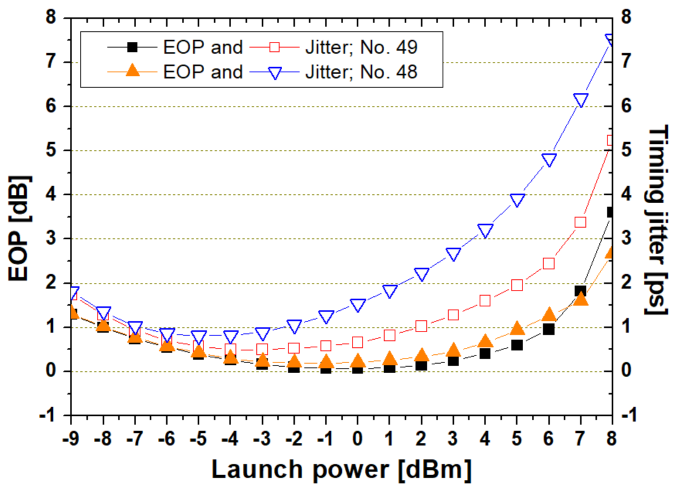


Figure 4. The EOP and timing jitter of pattern number 49 and 48 as a function of the launch power in case of random-inverse distribution.

The flexibility is included in the quality evaluation factor for the design of optical transmission links. The effective NRD range can be used as a measure to evaluate the

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flexibility of dispersion-managed link. In the analysis so far, the NRD was fixed at 10 ps/nm and analyzed, because this value can induce the best compensation. However, it has been confirmed through the previous studies that NRD can obtain a valid compensation even if it has a value larger or smaller than 10 ps/nm. Thus, the effective NRD range can be defined as the range from the minimum NRD to the maximum NRD at which 1-dB EOP can be achieved.

Figure 5 shows the effective NRD range in dispersion-managed link with each random distribution for which the best compensation is obtained. To be more specific, the results obtained for pattern number 28 in random-inverse distribution, and pattern number 48 in random-follow and all-random distributions are included in Figure 5. As can be seen intuitively, the effective NRD range shown in Figure 5 has a closed curve shape. It can be known that the larger the area of the closed curve, the greater the flexibility of link design. Consistent with the results obtained above, it can be confirmed that the flexibility of the dispersion-managed link design is excellent in the order of random-inverse, all-random, and random-follow.

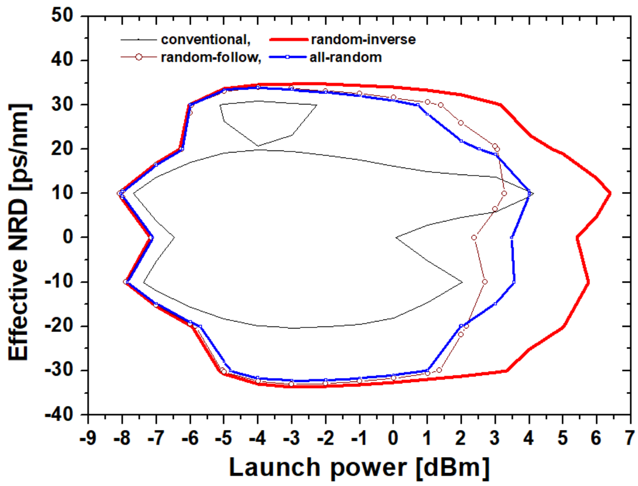

Figure 5. The effective NRD ranges versus the launch power.

In terms of performance, the area of the closed curve, i.e., the area of the effective NRD range is equivalent to the product of NRD and launch power. A total of 150 RDPS distribution patterns are considered in this study. However, it is difficult in terms of analysis to simultaneously express the effective NRD range for so many cases in one graph. An easy and convenient way to compare flexibility is to use the product of NRD and launch power for each random pattern.

Figure 6 shows the product of NRD and launch power for all distributions investigated in this paper. It can be confirmed that random-inverse distribution is the best in terms of the flexibility of the dispersion-managed link design. Moreover, it can be seen that the product of NRD and launch power for all random-inverse distribution patterns is larger than the conventional scheme (333.6 (ps/nm)·dBm).

As a result of the analysis of the product of NRD and launch power, it can be confirmed that the effective NRD range and the maximum launch power resulting 1-dB EOP may not be large at the same time even if the product is larger. That is, the design margin of each of the NRD and the launch power varies depending on the specific random pattern of the RDPS. Figure 7 shows the product and the maximum launch power that produces 1-dB EOP for each pattern simultaneously.

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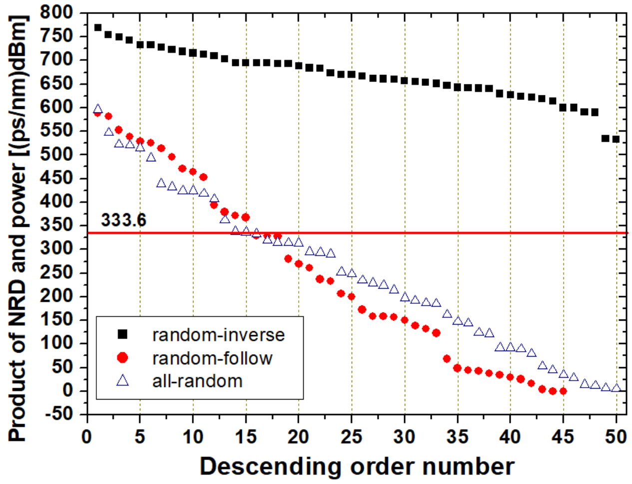
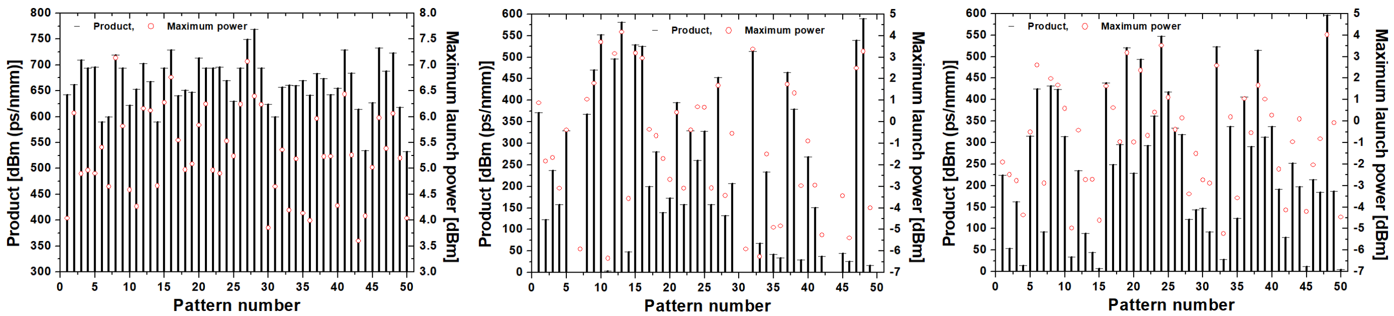


Figure 6. The product of NRD and launch power.

In the result of Fig. 7(a), the maximum launch power for pattern numbers 33 and 34 with similar product magnitudes are 4.2 dBm and 5.2 dBm, respectively, with a difference of about 1 dB. This result means that in the dispersion-managed link designed with pattern number 33, the NRD can be selected with margin as the maximum launch power is lower compared to pattern number 34. Among the random-inverse distributions, the best product characteristic is obtained by applying pattern number 28, and since the maximum launch power is not too large, NRD can be applied with sufficient margin when designing dispersion-managed link. On the other hand, in the dispersion-managed link designed by pattern number 8, the product characteristic is relatively good, but the maximum launch power is relatively large, thus it is difficult to apply NRD with margin. In conclusion, the RDPS pattern in the random-inverse distribution should be determined and applied according to the specific requirements such as NRD margin and power margin.



(a) (b) (c)

Figure 7. The product of NRD and launch power and the maximum launch power resulting 1-dB EOP. (a) random-inverse case, (b) random-follow case and (c) all-random case.

Figure 8(a) shows the dispersion maps made with the RDPS distribution pattern that can obtain the best compensation among random-inverse distributions that have superior compensation effects compared to others. On the other hand, Figure 8(b) shows the distribution maps made with the RDPS distribution pattern with the least compensation effect among the random-inverse distributions. Analyzing the dispersion maps shown in Fig. 8(a), it can be recognized that the amount of accumulated dispersion (i.e., positive value) and offsetting dispersion (i.e., negative value) is large intensively at the beginning and the end of the transmission path in common.

The optical pulse width in fiber spans in which the accumulated dispersion amount has positive value is broadened than the initial pulse width. As the width of the optical pulse is extended, the intensity of optical pulse is weakened, and as a result, it is less affected by the nonlinear Kerr effect. However, if the cumulative dispersion is maintained only as positive value in all fiber spans in order to be less affected by the Kerr effect, intersymbol interference (ISI) occurs due to the dispersion of optical pulses, which deteriorates the transmission quality. Therefore, it is necessary to make the cumulative dispersion amount negative at appropriate intervals. The dispersion maps shown in Figure 8(a) correspond to the shape following the aforementioned distribution of the accumulated dispersion.

On the other hand, the dispersion maps shown in Fig. 8(b) are also symmetric around the midway OPC, but show a different aspect from Fig. 8(a). In particular, the dispersion map generated by pattern number 43 has the positive cumulative dispersion in the front part of the former half and the negative cumulative dispersion in the rear part of the latter half, like the dispersion maps shown in Fig. 8(a). However, in this dispersion map, the overall shape of the accumulation and offset of the dispersion in each half link is generally wider than that in Figure 8(a).

The conclusion drawn from the analysis of Figure 8 is that the effective compensation can be resulted when the RDPS is randomly set to repeat the accumulation and offset of the dispersion in a relatively short period after the positive cumulative dispersion is concentrated at the beginning of the entire link. In addition to this, by setting the RDPS distribution order in the latter half link opposite to that in the former half, the effective compensation can be obtained.

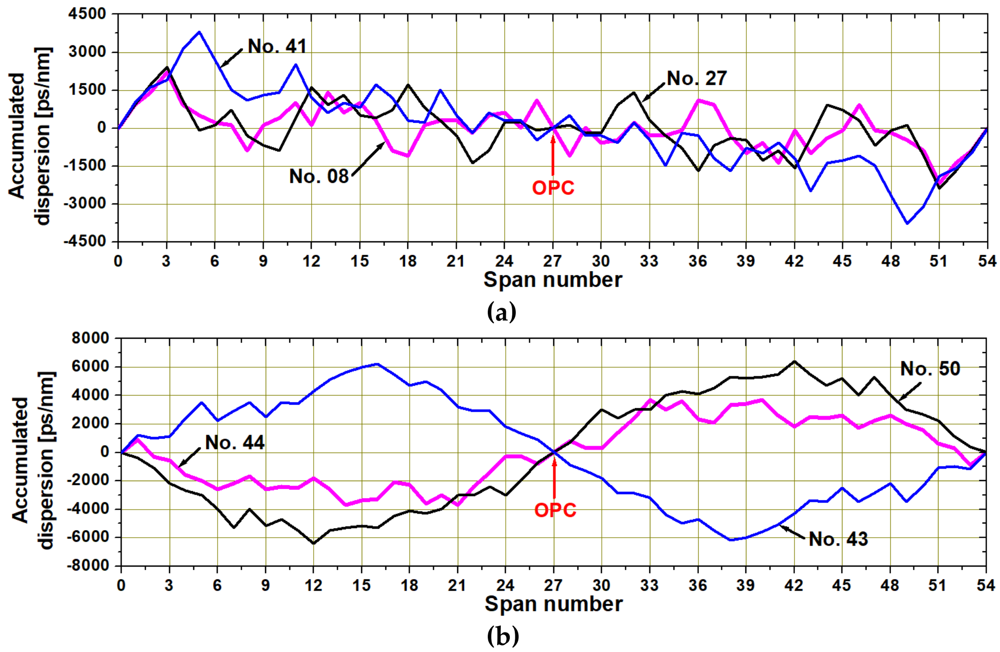


Figure 8. The dispersion maps established by random-inverse distribution of RDPSs. (a) the best compensation cases, and (b) the worst compensation cases.

5. Conclusions

Up to now, we have investigated three cases in which the RDPS of the fiber spans constituting the former half of the MSSI-based DM link are randomly distributed. The RDPS arrangement in the latter half was distinguished into the case of following the random distribution arrangement of those in the former half as it is (random-follow), the case of inverting those (random-inverse), and the case of random with a different pattern irrespective of the arrangement in the former half section (all-random).

It was confirmed that the compensation effect of the distorted WDM channel was improved overall in the link to which the dispersion map made of random-inverse distribution was applied, among the three cases. This result seems to be because the random-inverse distribution can establish more symmetrical distribution map with respect to the midway OPC. In addition, it was confirmed that the dispersion maps generated by the random-inverse distribution are much more advantageous than the other two distributions for the flexibility of the dispersion-managed link design.

The naive intention of this paper is to provide engineers with flexible dispersion map configuration without RDPS limitations in designing dispersion-managed link with midway OPC, and to provide a sufficient and selectable design margin at these links. The random distribution of the RDPSs proposed in this study, especially the random-inverse distribution, and the NRD margin and power margin in this configuration can be seen as a result that can sufficiently satisfy the purpose of our study compared to the existing link such as the conventional DM link.

However, it requires a lot of effort to randomly arrange the RDPS of the fiber spans consisting of the former half link so that acceptable compensation quality is derived, and even if such a random pattern is found, another nuisance may be that the RDPS arrangement in the latter half link has to be reversed to that of the former half.

Nevertheless, we think that the method of randomly distributing the RDPS of the fiber spans of the former half link and artificially constructing the RDPS distribution in the latter half is a new attempt to flexibly configure the dispersion-managed link and increase the compensation effect at the same time.

Furthermore, because we have specified the shape of the dispersion map based on random-inverse distribution that can further improve the compensation performance, it is expected to practically contribute to design and setup of the dispersion-managed link with the embedded midway OPC by using the detailed arrangement guidance and system margin of random RDPS induced in the process.

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Conflicts of Interest: The authors declare no conflict of interest regarding the publication of this paper.

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