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REDUCTION OF CROSSTALK IN WAVELENGTH DIVISION MULTIPLEXED FIBER OPTIC COMMUNICATION SYSTEMS

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Abstract—In this paper two new methods to reduce the crosstalk in WDM systems are presented. These two methods along with the present methods are analyzed and their performances are compared. The proposed methods yield better results. Both signal power and optical signal power to noise power ratio (OSNR) improve significantly.

1. INTRODUCTION

The researchers working in the area WDM based fiber optic systems are continuously trying to increase the information carrying capacity of such systems, in order to meet the ever increasing demand on the bandwidth. They are working very hard to increase the number of multiplexed channels, by decreasing the channel spacing, and increasing the bit (data) rate of a single channel. However, both these factors, decrease in the channel spacing and increase in the data rate, increases the crosstalk of the systems. Scientists are trying to reduce this crosstalk by employing several measures [1–6]. On way to reduce the crosstalk is to use return-to-zero (RZ) format in place of NRZ format. The RZ format in optical communications has advantages over the more frequently used non-return-to-zero format, mainly because the RZ-modulated signal can withstand better the impact of fiber nonlinearity and polarization-mode dispersion [13–15, 19–24]. Various schemes have been proposed to reduced the crosstalk due to the interference beating between adjacent channels wavelength-division-multiplexing (WDM) systems, the most widely used being the polarization interleaving method [16, 17]. However, for the very small channel spacing, the power leakage from one channel to its adjacent channels still remains. To reduce this leakage, one need to use filters with sharp spectral response, typically consisting of more than one stage- such filters are expensive, exhibit high insertion loss, and often cause large intersymbol interference (ISI). Kurgin et al. have shown that adjacent channel interference (ACI) can be reduced by the dispersion interleaving method [18]. This method utilizes the residual fiber dispersion to mitigate the interference from the adjacent channels. We here proposed modified versions of both the polarization interleaving and dispersion interleaving methods. We have analyzed all the four types of systems. The results prove that the proposed systems are superior.

2. POLARIZATION INTERLEAVED & DISPERSION INTERLEAVED WDM SYSTEMS

In WDM systems, after demultiplexer, amplitude of the signal incident on the nth detector is given by

$$E_n = S_n + \sqrt{\gamma}\,[S_{n+1} + S_{n-1} + S_{n+2} + S_{n-2} + \cdots] \tag{1}$$

where S_n is the amplitude of the signal in the nth channel and γ is the fraction of the optical power leakage from the adjacent channels into the nth channel.

The electrical current of nth detector will be proportional to $|E_n|^2$, i.e.,

$$\begin{aligned} i_n(t)\alpha|E_n|^2 \;=\; & |S_n|^2 + \sqrt{\gamma}\,[S_n \cdot S_{n+1} + S_n \cdot S_{n-1} + S_{n+1}S_{n-1} + \cdots] \\ & +\gamma\left[|S_{n+1}|^2 + |S_{n-1}|^2 + |S_{n+2}|^2 + |S_{n-2}|^2 + \cdots\right] \end{aligned} \tag{2}$$

The second term in (2) is the interference term that can be eliminated by means of polarization interleaving i.e., separating the odd and even channels and then polarizing them orthogonally, as shown in Fig. 1. The third term, the "power leakage" ACI, still remains. This can be minimized by using the RZ format and time interleaving the signals. The signals in the odd channels are delayed by a half-bit period relative to the signals in the even channels so that the peaks of all signal channels coincides with the valley of the their adjacent channels. Thus, the interference from the adjacent channels near sampling point is greatly reduced. Unfortunately, such interchannel synchronization is not practical. Therefore, for the completely asynchronous systems, there is always a chance that the peak of the signal channel and its adjacent channels coincide in time. This is the worst-case scenario that should be avoided. In case of asynchronous systems the amplitude of the adjacent channel leakage can be reduced by the process of dispersion-interleaving.

In dispersion interleaved system, the dispersion-compensating fiber (DCF) is removed from either the first or the last span of the link and placed at the transmitter side for the odd channels and at the receiver side for the even channels. As a result, the channel signals arrive at their receivers with dispersion fully compensated, while the ACI arrives either under or over compensated. So the leakage peaks get smoothed and the performance improves. Dispersion interleaving improves the results and the improvement is nearly independent whether the signal channel is completely synchronized or delayed by a half bit interval with respect to adjacent channel [18].

3. PROPOSED MODIFIED POLARIZATION & DISPERSION INTERLEAVED WDM SYSTEMS

In Polarization & Dispersion Interleaved WDM systems, as shown in Fig. 1, the total channels (N) are separated into two odd and even channels (of number $N/2$) in a single stage and then separated odd and even channels are multiplexed separately. In polarization interleaving (PI) systems, both odd & even channels are gone through different polarizations before interleaving. The separation of channels into odd and even channels improves capacity and spectral efficiency of WDM systems.

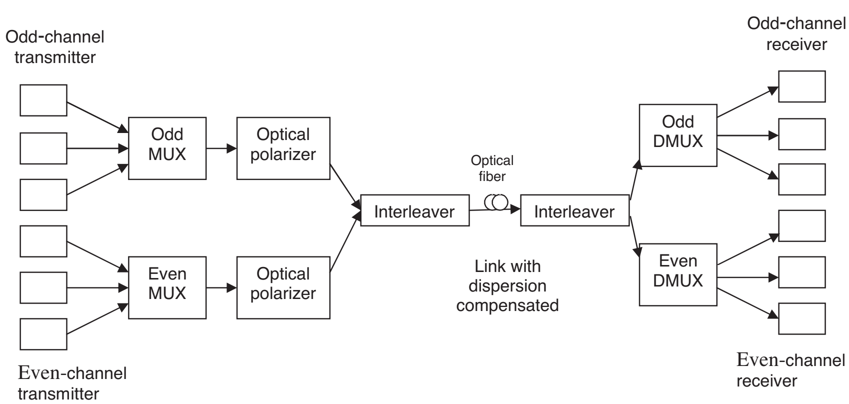


Figure 1. Polarization interleaved WDM system.

We have proposed some modifications in above mentioned PI and DI systems. Separation of total number of channels into odd and even channels is done in several stages instead of a single stage. In first stage, N channels are divided into two odd and even channels of number $N/2$. In second stage, each N/2 channel is again divided into two odd and even channels of number $N/4$. This process is continued till the divided odd and even channels have only one number.

We have designed the system for eight channels ($N = 8$). Total channels, designated as $n_1, n_2, n_3, n_4, n_5, n_6, n_7, n_8$, are first split into odd (n_1, n_3, n_5, n_7) and even channels (n_2, n_4, n_6, n_8). The channels n_1, n_3, n_5, n_7 are then divided into two channels, odd (n_1, n_5) and even (n_3, n_7). Similarly channels n_2, n_4, n_6, n_8 are divided into channels (n_2, n_6) and (n_4, n_8). Channels (n_1, n_5), (n_3, n_7), (n_2, n_6) and (n_4, n_8) are multiplexed in the first stage. Then in the second stage, channels (n_1, n_3, n_5, n_7) and channels (n_2, n_4, n_6, n_8) are multiplexed, as shown in Fig. 2.

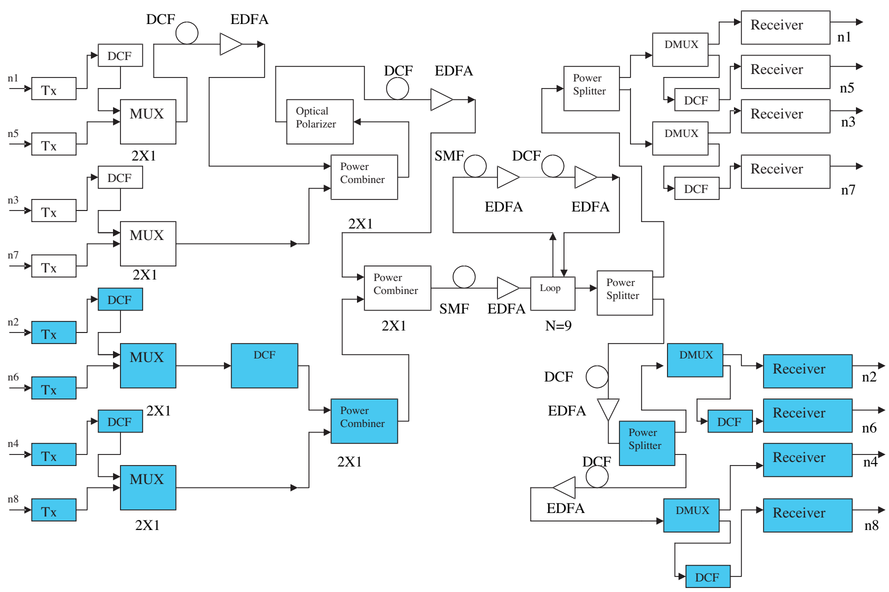


Figure 2. Modified dispersion interleaved WDM system.

4. SYSTEM DESIGN

We have designed PI, DI, modified PI and modified DI systems and the performance of all the systems has been measured, analyzed and compared. The optical signal to noise ratio (OSNR), optical signal power, noise power and eye patterns are taken as performance measured criteria. The link distance is taken as 800 km (10 fiber spans of length 80 km). The channels are multiplexed with channel spacing of 100 & 50 GHz with 193.1 THz as base frequency. The data rate of each channel is taken as 10, 20 & 40 Gb/s. All systems transmit WDM-RZ signals near 1550 nm. A single transmitter section (channel) consists of Mach-Zehnder modulator that accepts two inputs, one is from continuous wave laser producing stable carrier output near 1550 nm and other input is from return-to-zero line encoder which encodes the output derived from pseudo random bit sequence generator. Such eight sections are designed to generate and 8-channel WDM systems. Each span consists of 80 km of single mode fiber having a dispersion coefficient equal to 16 ps/nm/km. The propagation losses of the span are compensated by an EDFA with gain of 20 dB, dispersion is compensated with a dispersion compensating fiber of length 14 km and dispersion coefficient of −91.5 ps/nm/km. An EDFA of gain 6 dB is also used in order to overcome the losses offered by DCF. The modulated signals travel a total fiber length of 800 km in the designed link, and are passed through power splitter. The demultiplexed channels are finally passed through optical filter (Fabry-Perot), PIN photodiode followed by an electrical amplifier and a low pass Bessel filter.

In PI system eight channels are separated into two odd and even streams of four channels each. As shown as in Figure 1, the odd and even channels are routed through optical polarizer's having vertical and horizontal polarizations, respectively, before interleaving with each other.

In dispersion interleaved system, dispersion compensating fiber is removed from the first span. It is placed on the transmitter side for odd channels and in the receiver side for even channels. In doing so, the signals in all the channels are fully dispersion compensated, while ACI is partially compensated and it is smoothed out.

In the modified DI system the separation of 8 channels are done in two stages other things remain same. The complete setup of modified DI system is shown in Figure 2.

The modified polarization interleaved system is same as that shown in Fig. 2. The only difference is that all DCF's placed in transmitter and receiver sections are removed and all the fiber spans are fully dispersion compensated.

5. RESULTS AND DISCUSSION

The Signal power, noise power and OSNR are measured for all types of systems for bit rates 10, 20 and 40 Gb/s and channel spacing of 100 GHz and 50 GHz for all the channels. For 100 GHz channel spacing, the frequencies of 8 channels are taken as 193.1, 193.2, 193.3 193.4, 193.5, 193.6, 193.7 and 193.8 THz, respectively and for channel spacing of 50 GHz the channel frequencies are taken as 193.1, 193.15, 193.2, 193.25, 193.3, 193.35 193.4 and 193.45 THz.

It is observed that trend in measured values are almost same for all the channels. The measured values of signal power, noise power and OSNR at a particular channel for all four types of systems are shown in Tables 1–6.

Table 1. Signal power at 100 GHz channel spacing for different bit rate.

	Signal Power (dBm) 10 Gb/s	Signal Power (dBm) 20 Gb/s	Signal Power (dBm) 40 Gb/s
PI	5.8768935	5.2341389	5.045741
Modified PI	13.147501	12.3363	12.130544
DI	11.815258	11.171793	10.8545
Modified DI	17.815252	16.373244	15.93214

Table 2. OSNR at 100 GHz channel spacing for different bit rate.

	OSNR (dB) 10 Gb/s	OSNR (dB) 20 Gb/s	OSNR (dB) 40 Gb/s
PI	11.150181	10.507432	10.319061
Modified PI	16.68677	15.876675	15.672785
DI	13.013543	12.370077	12.05474
Modified DI	19.032826	17.620818	17.454655

Table 3. Noise power at 100 GHz channel spacing for different bit rate.

	Noise Power (dBm) 10 Gb/s	Noise Power (dBm) 20 Gb/s	Noise Power (dBm) 40 Gb/s
PI	-5.2732879	-5.2732927	-5.2733201
Modified PI	-3.5392695	-3.5403748	-3.5422413
DI	-1.1982853	-1.1982842	-1.1982892
Modified DI	-1.217574	-0.97034	-1.392515

Table 4. Signal power at 50 GHz channel spacing for different bit rate.

	Signal Power (dBm) 10 Gb/s	Signal Power (dBm) 20 Gb/s	Signal Power (dBm) 40 Gb/s
PI	5.8920996	5.3441498	5.2120313
Modified PI	13.277258	12.551763	12.299623
DI	12.100765	11.369321	11.139599
Modified DI	18.300542	17.453221	17.148595

Table 5. OSNR at 50 GHz channel spacing for different bit rate.

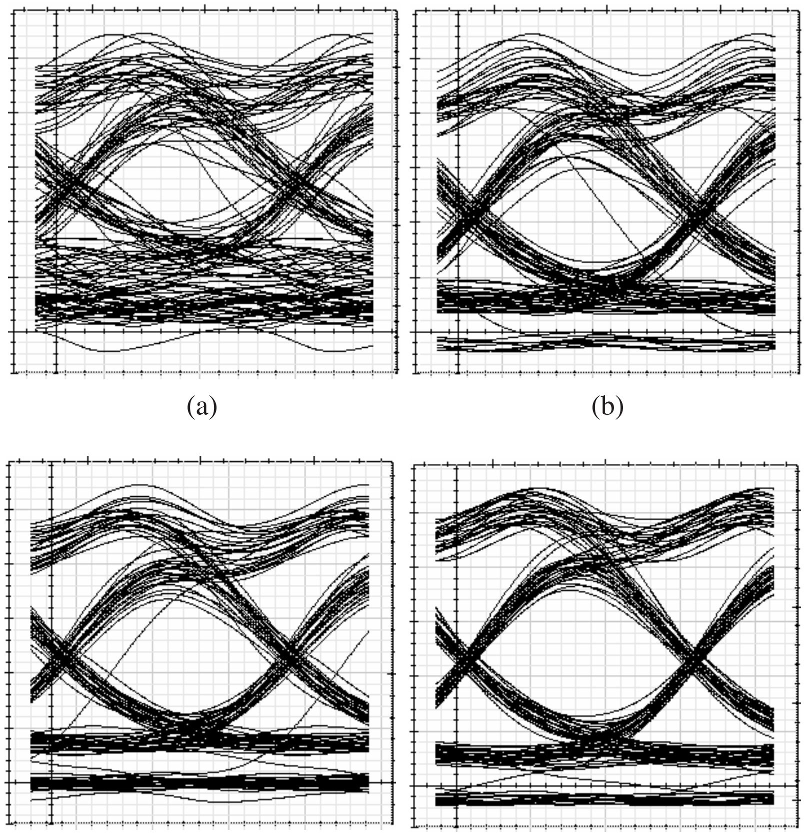
	OSNR (dB) 10 Gb/s	OSNR (dB) 20 Gb/s	OSNR (dB) 40 Gb/s
PI	11.133788	10.792551	10.660435
Modified PI	16.958235	16.236152	15.983795
DI	13.474184	12.742733	12.512997
Modified DI	19.636542	18.707432	17.629935

Table 6. Noise power at 50 GHz channel spacing for different bit rate.

	Noise Power (dBm) 10 Gb/s	Noise Power (dBm) 20 Gb/s	Noise Power (dBm) 40 Gb/s
PI	-5.2416885	-5.448401	-5.4484034
Modified PI	-3.6809769	-3.6843894	-4.1067816
DI	-1.3734187	-1.3734128	-1.3733982
Modified DI	-1.336405	-1.345432	-1.36345

Table 7. Improvement in signal power at 100 GHz channel spacing.

Improvement in Signal Power (dBm)	Bit Rates (Gb/s)		
	10	20	40
DI	5.9383645	5.9376541	5.810709
Modified PI	7.2706075	7.1021611	7.084863
Modified DI	11.938359	11.39106	10.886399



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

Figure 3. Eye pattern for channel spacing = 50 GHz and bit rate = 20 Gb/s
(a) Polarization interleaved system
(b) Dispersion interleaved system
(c) Modified polarization interleaved system
(d) Modified dispersion interleaved system.

Improvement in the performance of DI , modified PI and modified DI systems over PI system is calculated and results are given in Tables 7–10.

Eye patterns are also observed in each case and the observed patterns for 100 GHz channel spacing and 40 GBPS are shown in Fig. 3.

Table 8. Improvement in OSNR at 100 GHz channel spacing.

Improvement in OSNR (dB)	Bit Rates (Gb/s)		
	10	20	40
DI	1.863362	1.862645	1.735679
Modified PI	5.536589	5.369243	5.353724
Modified DI	7.882645	7.676153	6.836152

Table 9. Improvement in signal power at 50 GHz channel spacing.

Improvement in Signal Power (dBm)	Bit Rates (Gb/s)		
	10	20	40
DI	6.2086654	6.0251712	5.9275677
Modified PI	7.3851584	7.2076132	7.0874916
Modified DI	12.408442	12.109071	11.931221

Table 10. Improvement in OSNR at 50 GHz channel spacing.

Improvement in OSNR (dB)	Bit Rates (Gb/s)		
	10	20	40
DI	2.3403957	1.950182	1.852647
Modified PI	5.824447	5.4436014	5.3233597
Modified DI	8.5027536	7.854881	7.512492

6. CONCLUSIONS

It is observed that modified PI and modified DI systems are better than the PI & DI systems proposed earlier. The modified PI system is better than PI & DI systems. The modified DI system is the best among all four types of systems. There is a significant improvement in the performance of the modified systems. Both signal power and OSNR have improved significantly. Noise power also increases but increase in noise power is less than the increase in signal power. As a result OSNR increases considerably. The improvement in signal power and OSNR slightly decreases with increase in data rate and decrease in the channel spacing.

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