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Crosstalk reduction in dispersion-interleaved WDM systems

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To reduce the crosstalk, dispersion interleaved WDM systems is modified and analyzed. Hybrid Raman/Erbium-doped fiber amplifier is utilized for in-line compensation. The performance of modified dispersion-interleaved WDM system is evaluated with signal power, OSNR, noise power and eye-diagram. The modified system appears as a better means of crosstalk reduction.

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1. Introduction

The wavelength division multiplexing (WDM) is one of the most efficient techniques for increasing the information carrying capacity of an optical fiber communication system. The number of multiplexed channels is increased by reducing the channel spacing. The reduction in channel spacing increases the crosstalk and hence the performance of the system degrades considerably. There is continuous effort in scientific community to devise methods to decrease it [1-7].

The crosstalk due to leakage of adjacent channels, termed as adjacent channel interference (ACI) is a major problem in any WDM system. To reduce ACI part dispersion interleaving is a very powerful way. This utilizes the residual fiber dispersion to mitigate the interference from adjacent channels [5, 7-12].

In this contribution, dispersion interleaving method is considered for crosstalk reduction in WDM systems. The utilized system is modification of the system proposed by R.Tripathi et.al. In our system in-line amplification is carried out by hybrid Raman/Erbium-doped fiber amplifier. A combination of single-mode fiber (SMF) and reversed dispersion fiber (RDF) is used for Raman amplification. This results in better performance.

2. Theory

The leakage from adjacent channels is enhanced on decreasing the channel spacing in WDM systems. In such systems, the amplitude of the incident signal on nth detector (after demultiplexer) is given by,

$$E_n = S_n + \sqrt{\gamma}\left[S_{n+1} + S_{n-1} + S_{n+2} + S_{n-2} + \ldots\ldots..\right] \quad (1)$$

here S_n is the amplitude of the signal in the nth channel and γ is the fraction of the optical power that leaks from the adjacent channels. The electrical signal of nth detector is given as,

$$i_n(t) \approx E_n.E_n^* = |S_n|^2 + \sqrt{\gamma}\left[S_n.S_{n+1}^* + S_n.S_{n-1}^* + c.c.\right] + \gamma\left[|S_{n+1}|^2 + |S_{n-1}|^2\right] \quad (2)$$

The second term in equation (2) is the interference term and it can be eliminated by orthogonal polarization states of odd and even channels. The third term is responsible for power leakage from adjacent channels. This leakage can be minimized by using time interleaved signals in RZ format. 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 their adjacent channels. This results in significant reduction of interference from the adjacent channels near sampling point. 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 [5, 7].

In our proposed dispersion-interleaved system the in-line compensation is carried out by hybrid fiber amplifier. The finest amplification span length is one that facilitates the best trade-off between the low-cost requirements and stringent system performance. To maintain a good OSNR in long amplifier spans high input power is needed, which results in increased effects of nonlinearities. In such situation the transmission-system designers has to find best balance between the high OSNR and nonlinear impairments. The distributed Raman amplification (DRA) [13-14] may solve this problem. As compared to Erbium-doped fiber amplification scheme, DRA improves significantly the link's OSNR. Distributed Raman amplifier in combination with EDFA, i.e., Hybrid fiber amplifier, can be used for better control of nonlinear effects. Hybrid Raman/erbium-doped fiber amplifiers (HFAs) are promising technology for future WDM/DWDM multi-terabit systems. In our system reverse dispersion fiber (RDF) is used instead of dispersion compensating fiber (DCF). In DCF based Raman amplification systems pump power efficiency is very low and a significant amount of pump power is unused and wasted. This can be attributed to strong nonlinear effects in DCF [15-20].

3. System design

The proposed modified dispersion interleaved WDM system is shown in Fig. 1 and 2. In transmitter section, eight WDM-channels are taken and they are multiplexed with channel spacing of 100 GHz and 50 GHz at base frequency 193.1 THz. The data rate of each channel is taken as 20, and 40 Gb/s. Each transmitter section comprises a commercially available cw-laser at 1550 nm with line width 0.1 MHz. The pulse train is intensity modulated with a pseudorandom bit sequence (PRBS) of length 2^7-1 through a Mach-Zehnder modulator. For modified dispersion interleaved system, eight channels are divided in two sets of odd (n_1, n_3, n_5, n_7) and even (n_2, n_4, n_6, n_8) channels. These are again arranged in groups as: (n_1, n_5), (n_3, n_7), (n_2, n_6) and (n_4, n_8).

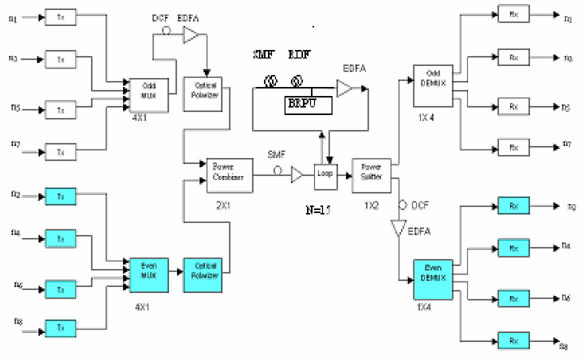


Fig. 1. Dispersion-interleaved system.

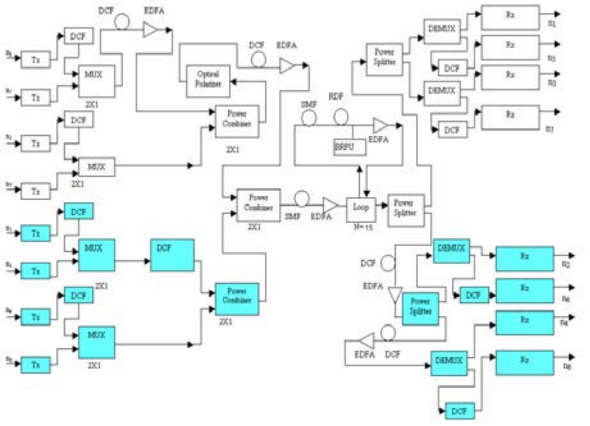


Fig. 2. Modified dispersion-interleaved system.

The signals from transmitter section propagated over 900 km fiber span consisting of 15 equal spans of SMF+RDF. Span losses are compensated by hybrid Raman/erbium-doped fiber amplifier. The fiber characteristics and parameters are given in Table 1. At the receiver end the signal is optically filtered with a low pass Bessel filter with band width four times the bit rate.

Table 1. Fiber parameters at 1550 nm.

Fiber Type	Group Velocity Dispersion (ps/nm/km)	Dispersion Slope (ps/nm^2/km)	Loss (dB/km)	Effective area(μm^2)
SMF	16	0.07	0.21	78
DCF	-90	-0.35	0.50	20
RDF	-16	-0.07	0.23	30

For in-line distributed amplification a hybrid Raman/erbium-doped fiber amplifier is simulated and optimized in 1530 nm to 1565 nm wavelength range. A 60 km (30 km SMF+30 km RDF) transmission fiber is pumped by a backward Raman pumping unit (BRPU) consisting of pumps at wavelengths 1440 nm and 1465 nm and pump powers are 120 mW and 60 mW respectively. The Erbium-doped fiber of length 8 m is forward pumped by 980 nm laser diode of pump power 12 mW. The gain and noise figure spectra of this system is given in Fig. 3.

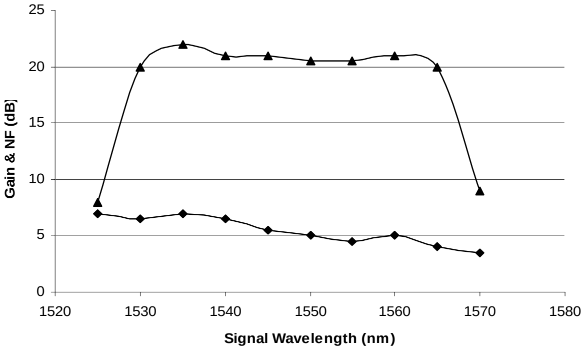


Fig. 3. Gain and noise figure of HFA for different signal wavelengths.

4. Results

For dispersion interleaved system with hybrid fiber amplifier (HFA) and modified dispersion interleaved system with HFA, the signal power, OSNR and noise power are measured. The channel frequencies for 100 GHz spacing are 193.10, 193.20, 193.30, 193.40, 193.50, 193.60, 193.70 and 193.80 THz. For 50 GHz spacing they are 193.10, 193.15, 193.20, 193.25, 193.30, 193.35, 193.40, and 193.45 THz. The amplitude of measured values at these frequencies is almost same. Therefore in order to save the space, signal power, OSNR and noise power at a particular channel (193.30 THz) for both systems are given in Tables 2-3. There is significant improvement in all parameters as compared to results produced by R. Tripathi et al. The optical eye-patterns for 100 GHz and 50 GHz channel spacing at data rates 20 Gbps and 40 Gbps are presented in Table 4-5. The observation of parameter values and eye-patterns shows considerable reduction in crosstalk and enhancement in performance of the modified system.

Table 2. Signal power, OSNR and noise power at 193.30 THz for 100 GHz spacing.

Parameters	DI with HFA	Modified DI with HFA
Signal Power(dBm) at 20Gb/s	13.27	17.78
Signal Power(dBm) at 40Gb/s	12.76	17.02
OSNR (dB) at 20Gb/s	15.77	25.69
OSNR (dB) at 40Gb/s	14.68	24.98
Noise Power (dB) at 20Gb/s	-3.78	-1.25
Noise Power (dB) at 40Gb/s	-3.92	-1.78

Table 3. Signal power, OSNR and noise power at 193.30 THz for 50 GHz spacing.

Parameters	DI with HFA	Modified DI with HFA
Signal Power(dBm) at 20Gb/s	14.37	19.18
Signal Power(dBm) at 40Gb/s	13.46	18.76
OSNR (dB) at 20Gb/s	15.98	21.12
OSNR (dB) at 40Gb/s	15.01	20.78
Noise Power (dB) at 20Gb/s	-3.82	-1.78
Noise Power (dB) at 40Gb/s	-4.18	-1.98

Table 4. Optical eye-diagrams for different bit rates at 100 GHz spacing.

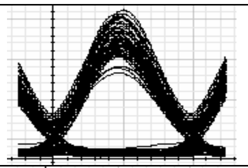
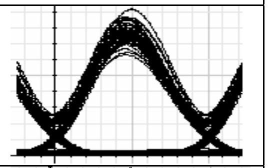
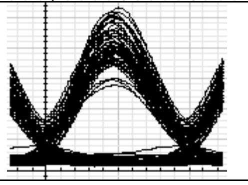
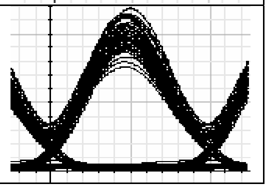
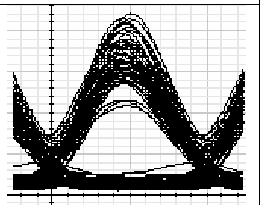
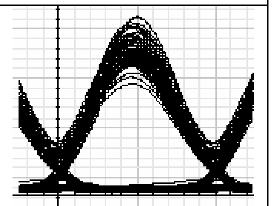
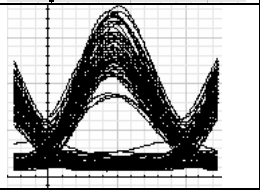
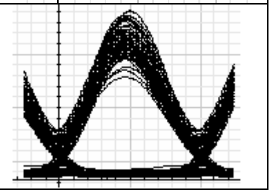
Bit rate	DI with HFA	Modified DI with HFA
20Gb/s		
40Gb/s		

Table 5. Optical eye-diagrams for different bit rates at 50 GHz spacing.

Bit rate	DI with HFA	Modified DI with HFA
20Gb/s		
40Gb/s		

5. Conclusion

The performances of dispersion interleaved (DI) and modified dispersion interleaved systems are evaluated by using hybrid fiber amplification technique. The signal power, OSNR, noise power, and optical eye-patterns are obtained for 100 GHz and 50 GHz channel spacing at 20 Gb/s and 40 Gb/s bit rate. Significant improvement in performance of the system and reduction in crosstalk, as compared to [7], is observed.

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