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IMPROVED CROSSTALK PERFORMANCE OF InP-BASED CROSS-CONNECT BY USING PHASE SCRAMBLING

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Abstract: We demonstrate a reduction in the effects of homodyne crosstalk in an InP-based 2x2 four WDM channel optical cross-connect by using a phase scrambling technique. By choosing an appropriate scrambling format, satisfactory transmission at a 2.5-Gbit/s bitrate is possible even though crosstalk levels are quite high, namely around -15 dB. We observed a small crosstalk penalty of less than 1 dB. This result demonstrates the feasibility of optical networking employing switching technologies such as cross-connects or add-drop multiplexers by tolerating relatively high crosstalk levels.

Introduction

All-optical WDM networks, comprising add-drop modules and/or cross-connects will employ optical components that may introduce crosstalk. Interferometric crosstalk arising from performance imperfections in (de)multiplexers and switches may result in large power penalties and bit-error rate floors [1]. Whereas a MEMS-based optical cross-connect (OXC) shows negligible crosstalk values, the switching speed is limited to the milliseconds region. InP-based OXCs have a potential in switching speed of a few nanoseconds, which makes them very attractive for packet switching applications. As a disadvantage, the InP-based OXCs still show moderate crosstalk figures [2], although considerable improvements have been published recently [3]. In continuation with the previous work [4], this paper describes an experimental investigation of high-frequency phase scrambling, applied simultaneously to a four channel WDM OXC chip [2]. An improved phase scrambling format, better than that used in [4], has been selected, which significantly mitigates the detrimental effects of homodyne crosstalk (interferers and signals have the same nominal wavelength).

Without phase scrambling the device showed poor performance due to interferometric crosstalk and bit error rate (BER) floors occurred at 10^-9. By applying a bandpass-limited noise source to the phase scrambling, error-free transmission with less than 0.5-dB power penalties is possible at a bitrate of 2.5 Gbit/s. This result demonstrates the feasibility of optical networking consisting of cross-connects or add-drop multiplexers whose crosstalk performance does not yet fully comply with the telecom requirements.

Experimental set-up

We used a four-channel InP-based 2x2 OXC as crosstalk generating device. The experimental set-up is shown in Fig. 1. Four DFB lasers provided CW sources at 1551.0, 1554.2, 1557.4, and 1560.6 nm. Pseudorandom NRZ data of 2^31-1 repeated length was encoded at a bitrate of 2.5 Gbit/s using an external LiNbO3 Mach-Zehnder modulator to generate optical signals with narrow spectra. The average extinction ratio of the modulated laser source was measured to be better than 20 dB. The four channels are subsequently scrambled in phase by the phase scrambler section to broaden its spectrum, and amplified by an EDFA before being split to create two paths for feeding both input ports of OXC. To obtain two uncorrelated input signals, we inserted a delay fiber in the setup, see Fig. 1a.

Fig. 1: (a) Experimental set-up, (b) OXC layout, and (c) Loss and Crosstalk performance

The delay fiber is chosen to be much longer than the coherence length of each laser source. Two polarization controllers are used to maximise the detrimental effects of interferometric beating noise in each channel. Combination of the power splitter and polarisation controllers creates in the setup a worst-case condition: wavelength and polarisation alignment. The experimental results represent, therefore, worst-case crosstalk performance that may occur
in WDM networks. For in- and out-coupling of the signals to and from the OXC, we adopted the same technique as in [5]. After travelling through the single-phase array OXC (Fig. 1b), the channels are amplified to compensate for fiber-to-fiber losses of 26 dB (Fig. 1c). The BER evaluation for each channel is done by an optical demultiplexer (bandwidth 90 GHz) for channel selection and a variable attenuator before the receiver for input power adjustment. The receiver consisted of an InGaAs PIN photodiode followed by a variable gain electrical amplifier to boost the photocurrent. The electrical bandwidth of the receiver circuit is 1.8 GHz, which is sufficient to detect 2.5 Gbit/s signals without significant signal distortion. The phase scrambling scheme is realised by using a phase modulator driven by a noise signal. The noise signal is made by mixing a 200-MHz band-limited white noise source with an RF signal. This scrambling format is an improvement of the form used in [4]. The obtained noise signal introduces a phase deviation of the value \( \tau \) and it is centered at 2.5 GHz. Spectra of the noise signal and the modulated signal after the phase scrambler (PS) are shown in Fig. 2. Compared with the original spectrum (No PS), there is a phase scrambler induced spectral broadening of 75 picometer (measured at -20 dB level) in the 2.5 Gbit/s signal spectrum. This spectral broadening will cause an additional penalty of less than 1 dB after 200-km long standard single-mode fiber due to chromatic dispersion [4].

Results

The penalties due to interferometric crosstalk in the OXC were measured by taking input powers corresponding to a BER value of \( 10^{-9} \). As reference the BER of a scheme without crosstalk (only one input port being used) is used. Measured optical crosstalk levels for all channels are depicted in Fig. 1c. It shows that the crosstalk levels are relatively high, i.e. \( \approx 15 \text{ dB} \) for channel 1 to \( \approx 17 \text{ dB} \) for channel 4. With these levels of crosstalk, optical systems will show BER floors indicating an unacceptable transmission performance [1,4]. Measured BER values are shown in Fig. 3 for (a) channel 1 and (b) channel 2 representing the outer and inner channel in WDM systems for three situations: no crosstalk \((\tau = \text{NoCrosstalk})\), crosstalk without phase scrambling \((\tau = \text{NoScrambling})\), and with phase scrambling \((\tau = \text{Scrambling})\). The solid curves have been obtained by curve fitting the measured values. The receiver sensitivity for both channels in case of no crosstalk \((\tau = \text{NoCrosstalk})\) is measured to be around \(-25.5 \text{ dBm} \) for BER=\( 10^{-9} \). When both inputs of OXC are used \((\tau)\), channel 1 performs slightly worse than channel 2 due to its larger crosstalk power (Fig. 1c). Their BER values show floors at \(10^{-9} \) and \(10^{-8} \) which indicates poor transmission performance. Using phase scrambling \((\tau)\), the detrimental effects of crosstalk are significantly mitigated such that the receiver sensitivity is enhanced to a value close to the case of no crosstalk. We measured a receiver sensitivity of \(-25 \text{ dBm} \). It means that the crosstalk penalty is reduced from very large values (corresponding to BER floors) to only 0.5 to 0.6 dB. BER evaluations on channel 3 and 4 showed a similar improvement if one uses this phase scrambling format. This small penalty of less than 1 dB shows that influences of ASE noise is limited by the narrow bandwidth of the optical demultiplexer as the channel selector.

Conclusion

We have experimentally shown that phase scrambling significantly mitigates the detrimental effects of interferometric crosstalk in a four-channel integrated cross-connect whose crosstalk performance is not acceptable for telecom applications. A substantial improvement in BER values from a BER floor of \(10^{-8}\) to a penalty of only \(0.6 \text{ dB} \) in the receiver sensitivity is demonstrated. This result shows very promising applications of phase scrambling for integrated cross-connects or add-drop multiplexers in WDM networks.

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References

Interferometric crosstalk reduction by phase scrambling in WDM integrated crossconnects

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Interferometric crosstalk mitigation in a four-channel 2.5Gbit/s InP-based WDM 2X2 cross-connect using phase scrambling is reported. Bit error rate performance is improved from a large power penalty indicated by a floor at $10^{-6}$ to a penalty of $<1$ dB.

Introduction: A phase scrambling (PS) technique has been investigated as a means for mitigating the detrimental effects of interferometric noise in optical links [1]. This type of noise may occur in integrated wavelength-selective devices such as InP-based optical cross-connects (OXCs). Owing to the compact size of a few millimetres and the switching speed of a few nanoseconds, the InP-based OXC is very attractive for packet switching applications. As a disadvantage, InP-based OXCs still show moderate crosstalk levels [2], although considerable improvements have been achieved recently [3]. A theoretical study of PS for a single-channel point-to-point transmission has been published in [4]. In this Letter, we report for the first time the application of the PS technique to a multi-channel 2X2 InP-based OXC in order to improve its performance. Without the PS, a 2.5Gbit/s bit rate waveform showed poor performance due to interferometric crosstalk and bit error rate (BER) floor occurred at $10^{-4}$. By using the PS, error-free transmission with a penalty of $<0.5$ dB is obtained. This result demonstrates clearly the potential of the PS technique in WDM networks, and in particular OXCs for which the crosstalk performance does not yet fully comply with the stringent telecom requirements.

Experimental setup: A four-channel integrated InP-based OXC was placed in the experimental setup (Fig. 1). Four DFB lasers provided CW sources at wavelengths of 1554.0, 1554.2, 1557.4 and 1550.6 nm. Pseudorandom non-return-to-zero (NRZ) data of a sequence length of $2^{20} - 1$ was encoded at a bit rate of 2.5Gbit/s using a phase scrambler to generate optical signals with narrow spectral. The four channels were subsequently scrambled in phase by the phase scrambler section to broaden their spectra, and amplified by an EDFA before being split to create two paths for feeding both input ports of the OXC. To obtain two uncorrelated input signals, we inserted a delay fibre in one arm before the input. The delay fibre was chosen to be much longer than the coherence length of each laser source. Two polarization scramblers were used to maximize the detrimental effects of interferometric beating noise. The combination of the power splitter and polarization scramblers created a worst-case condition in the setup: wavelength and polarization alignment. The experimental results represent, therefore, the worst-case crosstalk performance that may occur in WDM networks. To couple the signals into and out of the OXC, we adopted the same technique as [5]. After travelling through the single-phase array OXC, the channels were amplified to compensate for fibre-to-fibre losses. The BER evaluation for each channel was performed by an optical demultiplexer (bandwidth 90GHz) for channel selection and a variable attenuator before the receiver for input power adjustment. The receiver consisted of an InGaAs APD photodiode followed by a variable gain electrical amplifier to boost the photocurrent. The electrical bandwidth of the receiver circuit is 1.8GHz, which is sufficient to detect 2.5Gbit/s signals without significant signal distortion. The phase scrambler section was realised by using a phase modulator driven by a noise signal. The noise signal was made by mixing a 200MHz band-limited white noise source with an RF signal. The obtained noise signal caused a phase deviation of the value $\pi$ and it was centred at the RF frequency of 2.5GHz. The spectrum of the 2.5GHz signal due to the PS is shown in Fig. 2. Compared to the original spectrum, there is a phase scrambler induced spectral broadening of 75pm (measured at $-3$dB). This spectral broadening will cause an additional penalty of $<1$ dB after 200km standard fibre due to chromatic dispersion [4].

References
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References

Photonic conversion of OC-192 OTDM-to-4 × OC-48 WDM by supercontinuum generation
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The authors propose a novel method for converting optical time division multiplexed (OTDM) signals to wavelength division multiplexed signals (WDM) by using supercontinuum (SC), followed by spectrum slicing and time-gating. OC-192 (0.65GHz) OTDM signals to 4 × OC-48 (2.488GHz) WDM signals conversion is demonstrated. A BER of under 10-3 is experimentally demonstrated.

Introduction: At the network node between a high-speed backbone link and local area network (LAN), low-speed wavelength division multiplexed (WDM) signals have to be converted to high-speed optical time division multiplexed (OTDM) signals and vice versa, because the bit rates of the wide area network (WAN) and LAN may be different. Conversion between OTDM and WDM signals has been demonstrated by using four-wave mixing in semiconductor optical amplifiers (SOAs) [1], cross-gain compression of SOAs [2], and cross-phase modulation in a nonlinear loop mirror [3].

In this Letter, we propose photonic conversion of high-speed OTDM to low-speed WDM by SC generation, followed by spectrum slicing and time-gating. An OC-192 OTDM-to-4 × OC-48 WDM conversion is experimentally demonstrated.

Operation principle: The principle of operation of the proposed method is described below. OTDM signals generate an SC, producing multi-wavelength OTDM signals. After spectrum slicing the SC, they are time-gated.