

# Interferometric crosstalk reduction by phase scrambling in WDM integrated cross-connects

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## Interferometric crosstalk reduction by phase scrambling in WDM integrated cross-connects

E. Tangdionga, R. Jonker, H. de Waardt and G.D. Khoe

Interferometric crosstalk mitigation in a four-channel 2.5Gbit/s InP-based  $2 \times 2$  cross-connect using phase scrambling is reported. Bit error rate performance is improved from a large power penalty indicated by a floor at  $10^{-8}$  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 (OXC). 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 OXC 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  $2 \times 2$  InP-based OXC in order to improve its performance. Without the PS, a 2.5Gbit/s bitrate transmission showed poor performance due to interferometric crosstalk and bit error rate (BER) floors occurred at  $10^{-8}$ . 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 employing OXC 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 1551.0, 1554.2, 1557.4 and 1560.6nm. Pseudorandom nonreturn-to-zero (NRZ) data of a sequence length of  $2^{31} - 1$  was encoded at a bit rate of 2.5Gbit/s using an external modulator to generate optical signals with narrow spectra. 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 polarisation controllers were used to maximise the detrimental effects of interferometric beating noise. The combination of the power splitter and polarisation controllers created a worst-case condition in the setup: wavelength and polarisation 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 *pin* 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 2.5Gbit/s 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  $-20$ dB). This spectral broadening will cause an additional penalty of  $< 1$  dB after 200km standard fibre due to chromatic dispersion [4].

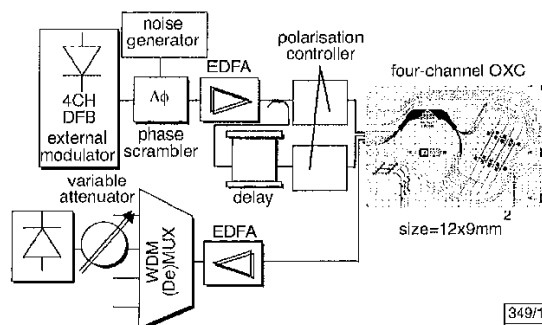


Fig. 1 Experimental setup

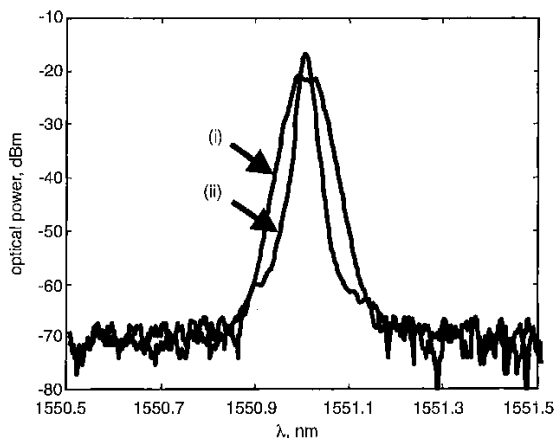


Fig. 2 Signal spectrum

- (i) due to phase scrambling
- (ii) original spectrum

**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 a reference, the BER of a scheme without crosstalk (only one input port being used) was used. Measurement of the static transmission properties of the OXC showed that the

fibre-to-fibre losses are ~26dB and that the crosstalk levels are quite high, varying from -15dB for channel 1 to -17dB for channel 4. The measured BER values are shown in Fig. 3 for channel 1 (a) and channel 2 (b), representing the outer and inner channel in WDM systems for three situations: no crosstalk, crosstalk without PS, and crosstalk with PS. The solid curves were obtained by curve fitting the measured values. The receiver sensitivity for both channels in the case of no crosstalk (○) was measured to be around -25.6dBm for BER = 10<sup>-9</sup>. When both inputs of the OXC were used (◇), channel 1 performed slightly worse than channel 2 due to its larger crosstalk level. Their BER values show floors at 10<sup>-7</sup> and 10<sup>-8</sup>, respectively, which indicates poor transmission performance. By using PS (△), the signal spectra were slightly widened so that a part of the signal-crosstalk beat power was moved to the frequency spectrum outside the receiver bandwidth. The detrimental effects of the beat power were significantly mitigated such that the receiver sensitivity was enhanced to a value close to the case of no crosstalk. We measured a receiver sensitivity of -25dBm. This means that the crosstalk penalty was reduced from a very large value (corresponding to the BER floor) to 0.6dB with an increase in the spectral width of only 0.075nm. BER evaluations of channels 3 and 4 showed a similar improvement if the same PS format is used. The effectiveness of this PS technique is only limited by the interplay between the spectral widening and the fibre chromatic dispersion on the one hand and the WDM channel spacings on the other hand. Wider spectra will not only introduce a larger dispersion penalty, but they may also exceed the very small channel spacings in a dense WDM network.

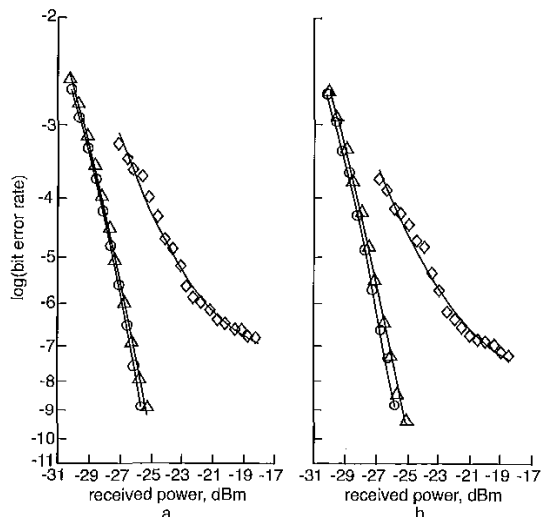


Fig. 3 Bit error rate performance

- a Channel 1
- b Channel 2
- no crosstalk
- ◇ crosstalk
- △ crosstalk and phase scrambling

**Conclusion:** We have demonstrated the effectiveness of the phase scrambling technique in mitigating the detrimental effects of interferometric crosstalk in an integrated WDM cross-connect. A substantial improvement in BER values from a BER floor of 10<sup>-8</sup> to a penalty of only 0.6dB in the receiver sensitivity was experimentally shown. This result shows that phase scrambling enables us to work with WDM devices whose performance is degraded by relatively high crosstalk levels.

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## Photonic conversion of OC-192 OTDM-to-4 × OC-48 WDM by supercontinuum generation

T. Hashimoto, H. Sotobayashi, K. Kitayama and W. Chujo

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 (9.953 Gbit/s) OTDM signals to 4 × OC-48 (2.488 Gbit/s) WDM signals conversion with a BER of under 10<sup>-9</sup> 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.

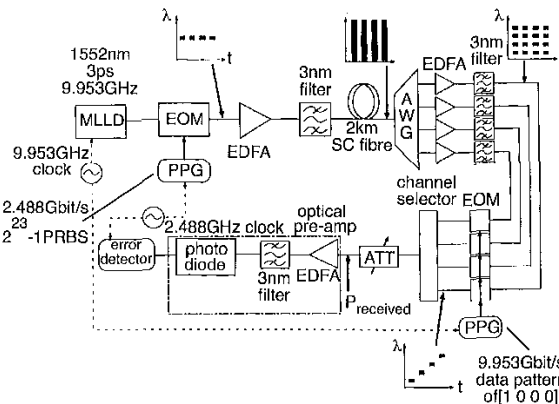


Fig. 1 Experimental setup of OC-192 OTDM-to-4 × OC-48 WDM photonic conversion

**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