Define statistics U

$$U = \frac{\hat{\mu} - 0}{\sigma}\sqrt{M} \quad (5)$$

If H_0 is true,

$$U \simeq N(0,1) \quad (6)$$

where $N(0,1)$ stands for a zero-mean, unit variance Gaussian distribution, and $\sigma^2 = 0.5$. We will use the statistic U to detect non-Gaussian stationary signals $s(n)$ in Gaussian noise. The Neyman-Pearson test for a significance level (false-alarm probability) α turns out to reject H_0, if $U > U_0$. The threshold U_0 is such that $\Pr(U > U_0) = \alpha$.

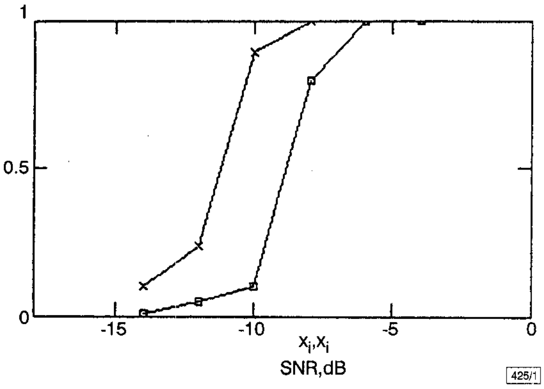

Fig. 1 *Probability of detection*

—×— $p1(x)_i$ = bispectrum U detector
—□— $p2(x)_i$ = bispectrum χ^2 detector

We selected $N = 1024$ with $L = 128$, $K = 8$ and $M = 900$. The noise $\{w(n)\}$ was taken to be zero-mean, white Gaussian noise. We estimated the bispectrum of the received data using the averaged method, rather than the smoothing method. Fig. 1 presents the results of the detection described above with $\alpha = 0.01$ based 100 Monte Carlo runs. SNR = $10\text{Log}\ \sigma_s^2/\sigma_w^2$. The proposed detector provides roughly 3dB of processing gain compared to the conventional bispectrum χ^2 detector.

Conclusions: This Letter presents a method for detecting non-Gaussian stationary signals in Gaussian noise using a bispectrum. The simulation experiments show that the performance of the proposed detector compares favourably to that of conventional bispectrum χ^2 detectors.

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Eight-channel bidirectional WDM add/drop multiplexer

Keang-Po Ho and Shien-Kuei Liaw

The authors propose and demonstrate an eight-channel reconfigurable bidirectional wavelength division multiplexed (WDM) add-drop multiplexer in which all channels can be added/dropped independently in either direction. The performance of the bidirectional WDM add/drop multiplexer is experimentally studied for a data rate of 10Gbit/s per channel, providing an overall capacity of 80Gbit/s. It is found that the performance of the add/drop multiplexer is not degraded by a backward propagating signal.

Introduction: Reconfigurable wavelength division multiplexed (WDM) networks can be employed to provide cost effective, flexible capacity growth [1–7]. Each WDM channel is transparent to signal format, bit rate, and protocol, to a certain degree. One important element in optical networks is the WDM add/drop multiplexer (WADM), especially in a ring topology. To date, most WADMs are unidirectional, i.e. the optical signal must add/drop in the same direction [4–9]. The purpose of this work is to demonstrate a bidirectional WADM. Because the signal can be added/dropped in either direction, only a single fibre is required for bidirectional transmission.

For a unidirectional ring, a signal must pass through all fibre nodes to reach the upstream node. A bidirectional ring can increase throughput because the signal can pass through a smaller number of hops to reach some of the fibre nodes. For an N-node ring with identical traffic pattern for each node, the average number of hops for a connection is ~$N/4$ for a bidirectional ring and ~$N/2$ for a unidirectional ring, resulting in an ~two-fold improvement in throughput using the bidirectional WADM.

WADM configuration: Fig. 1 shows the achitecture of the bidirectional WADM. The WADM consists of two eight-wavelength WDM multiplexer/demultiplexer (MUX) pairs similar to those designed for the MONET project [4, 7–9]. The WDM-MUX is a multilayer interference-filter-based demultiplexer with 1.6nm (200GHz) of channel spacing [8, 9] which is the same as the ITU draft standard. In the WADM, each wavelength channel has an EDFA to boost the power to the saturated EDFA power before the WDM MUX. Gain-equalisation is not required [4] for this bidirectional WADM as long as the losses at each channel of the WDM MUX are identical.

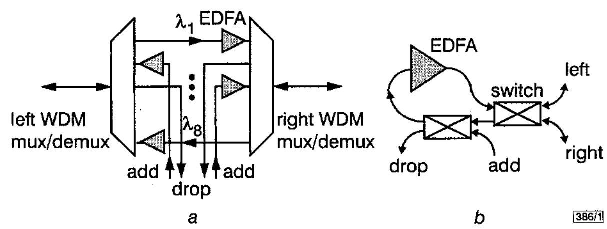

Fig. 1 *Architecture of bidirectional eight-wavelength WADM and structure of switch fabric at each wavelength port*

a Achitecture of WADM
b Structure of switch fabric

Fig. 1*b* shows the structure of the switch fabric at each wavelength port. There are two optical cross switches in each switch fabric. The first cross switch determines the direction of the signal, and the second switch determines whether the signal should be added/dropped or passed through the WADM directly. Fig. 1*a* shows some typical functions of the bidirectional WADM. The WADM can be configured to four states and the signal can be added/dropped to/from the left or right hand side of the network or passed through the WADM in each direction (from left to right or from right to left). The same wavelength cannot be transmitted bidirectionally in the same link. The same wavelength cannot be added/dropped together from both directions.

A bidirectional WADM is constructed with EDFAs having a saturated output power of +10dBm. The loss of the WDM MUX is ~2.5dB, resulting in +7.5dBm output optical power per channel. In the current WADM, an externally modulated 10Gbit/s transmitter is employed, resulting in a total capacity of 80Gbit/s. With a receiver sensitivity of ~–17dBm and a loss of 2.5dB from the WDM MUX, the link budget is ~23dB. If further link budget is required, the WADM structure can be employed as a bidirectional in-line amplifier to pass all channels without add/drop function [10].

Performance: The major issue in bidirectional transmission is the backward propagating light generated by Rayleigh backscattering, stimulated Brillouin scattering (SBS), and other reflection effects [10–12]. Rayleigh scattering is a fundamental loss mechanism arising from random density fluctuations frozen into the fibre core during manufacturing. SBS is a nonlinear effect that can generate a backward-propagating Stokes wave carrying most of the input energy. SBS can be eliminated by broadening the linewidth of the transmitter [13]. Other reflection effects may include reflections from fibre splices, connectors, or other optical components. The light travelling backward goes toward the WADM. While the backward light returning through the same wavelength port can be eliminated by the isolators in the EDFA, isolators cannot be employed in the bidirectional link. The WDM MUX requires a high crosstalk rejection to eliminate crosstalk from the backward propagating light of adjacent channels. Note that the launched power of each wavelength channel is high; the received optical power from another direction is usually much smaller after going through a length of fibre. A bidirectional WADM may therefore require a higher crosstalk rejection than a unidirectional WADM.

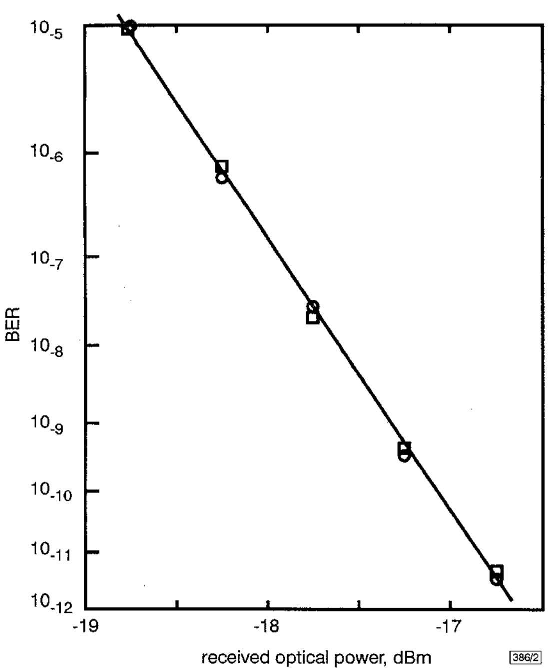

Fig. 2 *BER against received optical power for 10Gbit/s signal at λ_3 with and without counter-propagating adjacent channels*

□ without adjacent channels
○ with adjacent channels

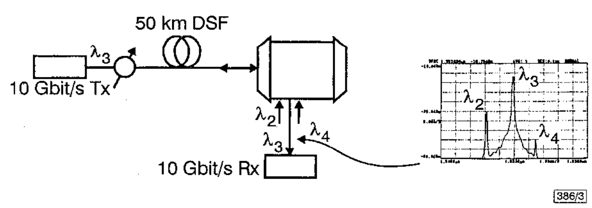

Fig. 3 *Experimental setup to evaluate impact of backward propagating light on performance of WADM*

Optical spectrum taken when BER of 10Gbit/s signal is $\sim 10^{-9}$

Fig. 2 shows the impact of backward-propagating light studied by sending λ_3 = 1552.69nm in one direction and the adjacent channels in the counter-propagating direction. The measurement setup is shown in Fig. 3. The WADM is connected to 50km of dispersion-shifted fibre (DSF) to simulate the effect of Rayleigh backscattering and other reflection effects. The 10Gbit/s signal of λ_3 is sent from the end of 50km of fibre and an optical attenuator for sensitivity measurement is located at the transmitter to eliminate its effects on the backward propagating light. The signals at λ_2 = 1550.92nm and λ_4 = 1554.25nm are both externally modulated. The laser is frequency modulated to broaden the linewidth for SBS suppression [13]. Fig. 3 also shows the optical spectrum at the λ_3 port when the BER of the 10Gbit/s signal is $\sim 10^{-9}$. While the crosstalk level is ~–18dB from λ_2, the crosstalk from backward-propagating light has no effect on the BER performance of the signal channel (as shown in Fig. 2). Note that the WDM-MUX is not symmetric [8] and the crosstalk from λ_2 and λ_4 are not equal. To study whether the bidirectional WADM requires greater crosstalk rejection, further measurements show that if all WDM channels propagate in the same direction, the crosstalk from adjacent channels is < –25dB.

Conclusion: An eight-wavelength bidirectional WADM with 80Gbit/s capacity is proposed and studied. The WADM includes wavelength add/drop capability in both directions using WDM demultiplexers. It is shown that the backward-propagating light does not induce a power penalty.

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