Optical Add-Drop Multiplexer Based on Fiber Bragg Gratings for Dense Wavelength Division Multiplexing Networks

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Abstract

A configurable optical add-drop multiplexer (OADM) based on fibre Bragg gratings is reported. Dynamically selection of the add-drop or pass-through functionality is realised according to the control of an optical switch. The OADM performance measurement realised in a 70 km, 3 × 2.5 Gb/s channels dense wavelength division multiplexing (DWDM) experimental network are reported and the results compared with simulated ones. The OADM tolerance to channel spacing and detuning were also studied.

I. INTRODUCTION

The enormous grow in the demand of bandwidth is pushing the utilisation of fibre infrastructures to their limits. To fulfil this requirement the constant technology evolution is substituting the actual single wavelength systems connected in a point-to-point topology by dense wavelength division multiplexing (DWDM) systems, creating the foundations for the Optical Transport Network (OTN). The objective is the deployment of a optical network layer with the same flexibility as the equivalent SDH, because it is more economical and allows a better performance in the bandwidth utilisation. Optical add-drop multiplexers (OADM) are the simplest elements to introduce wavelength management capabilities by enabling the selective add and drop of optical channels.

A DWDM network with a static OADM may provide a reliable, cost effective and scalable network, since the static OADM is based on low-loss, low-cost passive devices and does not need any power supply.

Several OADM's have been proposed based on arrayed wave-guide gratings (AWG) [1], Fabry-Perot filters [2], combination of dielectric thin film MUX and DEMUX [3], Bragg gratings written in Mach-Zehnder interferometers [4] and fibre Bragg gratings (FBG) with 2 optical circulators [5]. We propose a more economical and transparent OADM architecture with just an optical circulator.

The basic architecture of the OADM node presented consists of a FBG, an optical circulator, a power combiner and an optical switch. At first, *N* multiplexed wavelengths are led to the Bragg grating through the circulator, then the filtered signal is reflected and goes back to the circulator where it is removed. The remaining channels are coupled with the added channel in a power combiner. The optical switch allows the selection of the add–drop operation with the remotion and addition of a channel or a pass through operation, where the removed channel is added again.

II. OADM IMPLEMENTATION

The functionality of the OADM is demonstrated using the experimental network in figure 1. Three distributed feedback lasers (DFB) based at the ITU grid of 200 GHz (≈ 1.6 nm) spacing with wavelengths of 1549.32 nm, 1550.92 nm (dropped channel) and 1552.52 nm, were externally modulated, through a Ti:$LiNbO_3$ Mach-Zehnder intensity modulator, at 2.48832 Gb/s (STM-16) with a non-return to zero (NRZ) 2^7–1 pseudo random bit sequence (PRBS). In the experimental transmission WDM link, 70 km of single mode standard fibre are used. Two Erbium doped fibre amplifiers (EDFA) having saturated output powers of 13 and 17 dBm and noise figures smaller than 4 dB are employed to provide the required power to compensate the link and OADM losses.

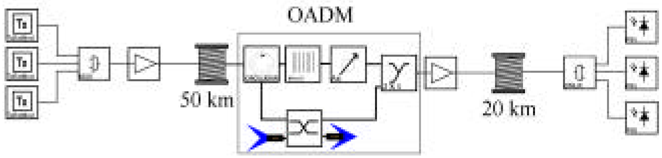

Figure 1 – Scheme of the OADM and experimental transmission DWDM network.

The performance of the OADM is related with the spectral characteristics of the fibre Bragg grating. In figure 2 is plotted the reflection spectra of the FBG coupled to the optical circulator.

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The isolation and crosstalk of the optical circulator are greater than 60 dB and the FBG has a central reflective wavelength of 1550.92 nm, with 0.73 nm and 1.388 nm for the -3 dB and -20 dB bandwidth, respectively. The rejection of the FBG for the adjacent channels is -28.1 dB (as can be seen on figure 4) and the transmission of the central wavelength is -30.7 dB (as can be seen on figure 5) bellow the remaining channels, which corresponds to a 99.99 % reflectivity. The optical switch isolation is greater than 60 dB.

The use of high isolation components allows the reduction of signal degradation due to crosstalk.

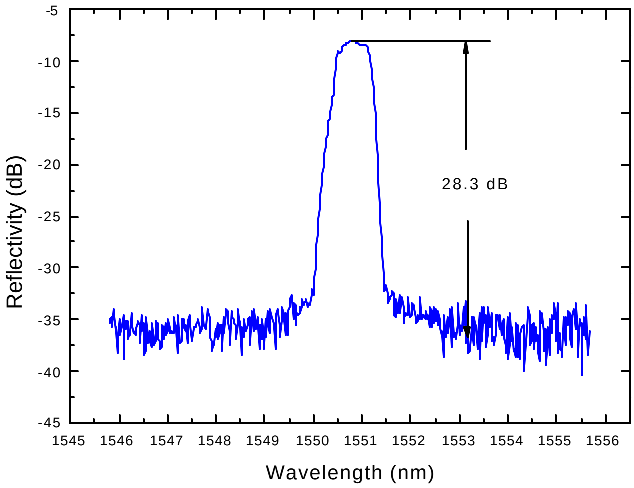

Figure 2 – Reflection spectra of the FBG.

The through and add-drop operation mode requires a channel-by-channel level equalisation in order to keep the optical power level of all the WDM output signals constant, and therefore avoid the signal-to-noise (SNR) degradation. To provide a level equalisation capacity, on the trough operation mode, a 40 % - 60 % optical power combiner is used and in order to achieve a precise equalisation an optical attenuator is positioned between the FBG and the 40 % input port of the power combiner. On the add-drop operation mode the power equalisation is realised by the direct adjust of the add signal optical power.

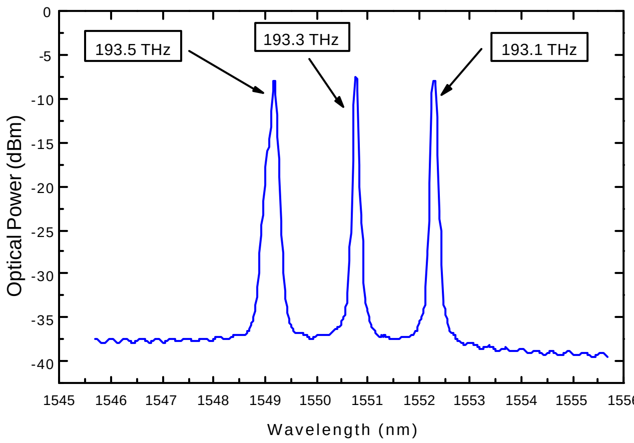

Figure 3 – Input signal at the OADM

Figures 3, 4, 5 and 6 show the spectral characteristics of the OADM and respectively present the power spectra of the input WDM signals, the dropped signal, the passed trough signal without re-adding and the output signal. The two small signal components present with the dropped signal (figure 4) are due to residual reflections on the circulator and on the FBG

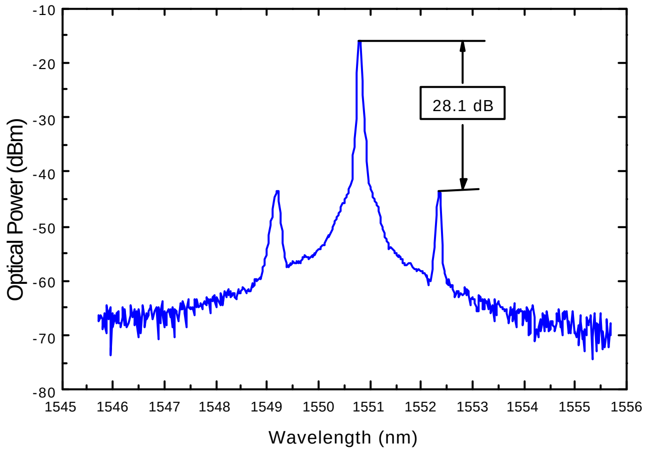

Figure 4 – Dropped signal.

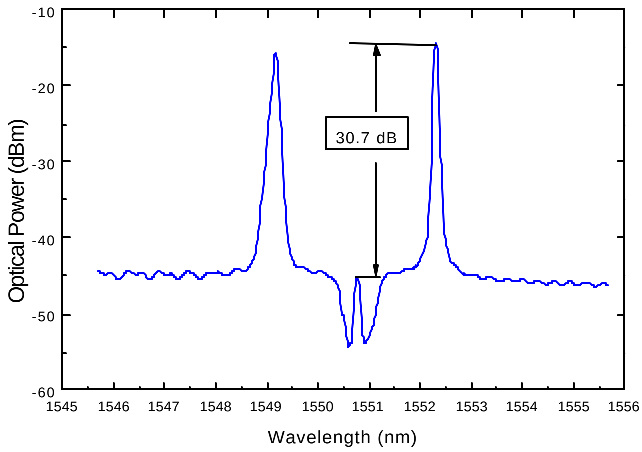

Figure 5 – Passed thought signal without re-adding.

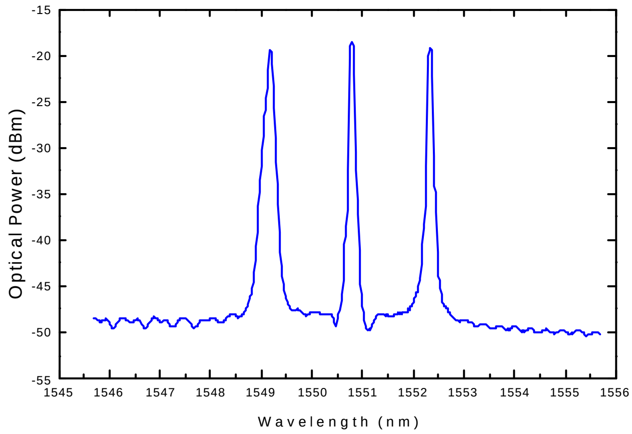

Figure 6 – Output signal with an added channel.

The small spectral component at 193.3 THz (dropped channel) on the pass-through signal (Figure 5) results from the imperfect reflection of the central wavelength by the FBG.

The OADM insertion loss is 6.0 dB for all the input channels regardless of the node operation node (add-drop or pass-through). The loss for the drop and for the add channel is 3.8 dB and 3.5 dB, respectively.

A fundamental difficulty of wavelength routing is the crosstalk from neighbouring inputs, which cause severe degradation in the system performance. The performance of our network is assessed by the BER measurements on the central wavelength channel (193.3 THz).

Figure 7 shows the BER performance against the receiver power, for the back-to-back operation (0 km), for the drop channel on the OADM after propagation on 50 km of fibre and for the same channel just after propagation on 50 km of fibre (without be dropped at the OADM). The BER floor and the 10^{-9} BER are also indicated.

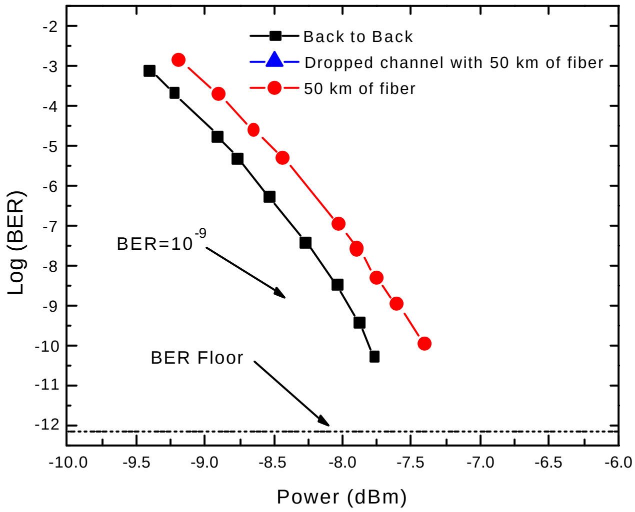

Figure 7 – BER performance for the dropped channel.

The power penalty measured at a 10^{-9} BER is 0.08 dB, for the dropped channel at the OADM compared with the same channel at the OADM input after propagation on 50 km of fibre. This power penalty is due to heterodyne crosstalk induced by the leak of the signal power from the two neighbour signal components in figure 4. These residual components interfere with the detection process, resulting in noise addition on the detector.

Figure 8 shows the detected eye diagram of the OADM dropped channel, for a 10^{-9} BER. In this case, a direct-detection without receiver electrical filter was used.

The performance of the OADM added channel was also investigated. Figure 9 shows the BER performance against the receiver power, for the back-to-back operation (0 km), for the added channel on the OADM after propagation on 20 km of fibre and for the same channel just after propagation on 20 km of fibre (without being add at the OADM).

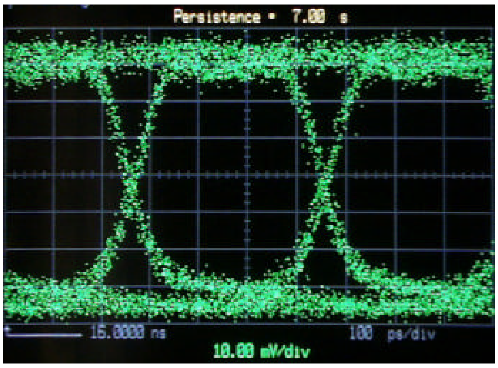

Figure 8 – Eye diagram for the dropped channel.

The power penalty measured at a 10^{-9} BER is 0.18 dB, for the added channel at the OADM compared with the same channel just after propagation on 50 km of fibre. This power penalty is due to homodyne crosstalk induced by the small leakage signal at the same wavelength resulting from incomplete filtering of the dropped channel (figure 5). This crosstalk is far more penalising that the heterodyne due to its coherent nature.

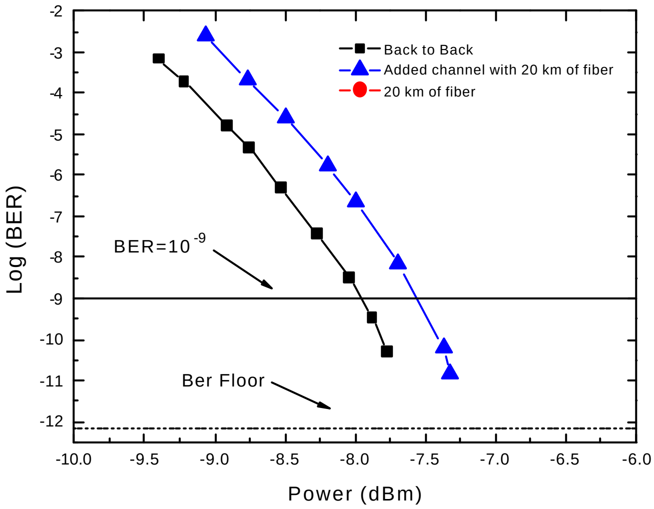

Figure 9 – BER performance for the added channel.

As verified in figures 7 and 9, the inclusion of the OADM in the experimental network does not degraded significantly the signal performances.

III. OADM TORELANCES

The tolerance of the OADM to the channel spacing was investigated. The power penalty due to channel spacing was measured keeping the central wavelength fix and approaching the other two channels.

The power penalty for the channel spacing for which the FBG was design (200 GHz) was considered 0 dB.

In figure 10 are shown the results of the power penalty, the full width bandwidth at -1, -3 and -20 dB are also shown.

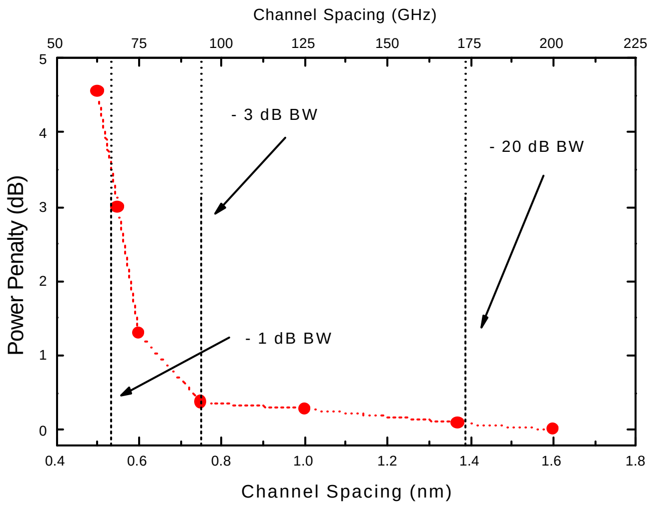

Figure 10 – Power penalty of the removed channel as functions of the channel spacing.

As the channel spacing decreases the power penalty increase due to heterodyne crosstalk, since the rejection of the FBG to the adjacent channel decreases. Nevertheless the OADM has been specified for a channel spacing of 200 GHz, the use of a 100 GHz spacing will increase the power penalty to less than 0.25 dB [6].

The tolerance of the OADM to the channel detuning was also investigated. The power penalty for the added channel due to the wavelength detuning of the removed and added channel with the central wavelength of the FBG, was measured. The power penalty for a 0 nm detuning was considered 0 dB.

These results are presented in figure 11, the full width bandwidth at -0.5 dB are also shown.

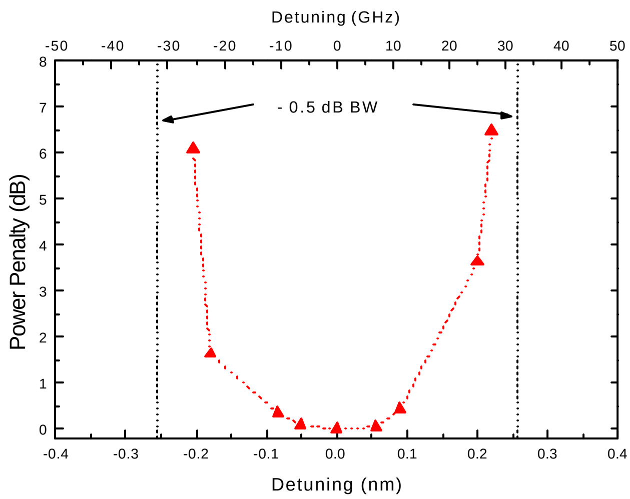

Figure 11 – Power penalty of the removed channel as functions of the channel spacing.

As the channel detuning between the added channel and the FBG increases the power penalty increases due to homodyne crosstalk, since the rejection of the FBG to the central channel decreases. The wavelength tuning of the lasers with the FBG is a crucial aspect to keep the performance of the OADM at a reasonable level, since a detuning of ± 0.15 nm will result on a power penalty of 0.5 dB to the added channel. This value is considerable high if we intend to cascade several OADM in the network.

IV. SIMULATION

The 70 Km SMF experimental network with the OADM was simulated in a photonic transmission simulation program, *PTDSÓ*. The input power into the fibre was maintained below 3 dBm to exclude the nonlinear effects in fibre, so that we can obtain transmission performance mainly depending on the crosstalk of the OADM and fibre chromatic dispersion. In order to estimate BER characteristics by simulation a gaussian assumption for the noise and a total of 1024 data bits were used.

Figure 12 displays the BER performance for the dropped simulation channel, obtained in the same condition as the experimental measurements (figure 7).

The power penalty of the simulation network dropped channel, extrapolated for a 10^{-9} BER is comparable to the experimental results, within the experimental uncertainty.

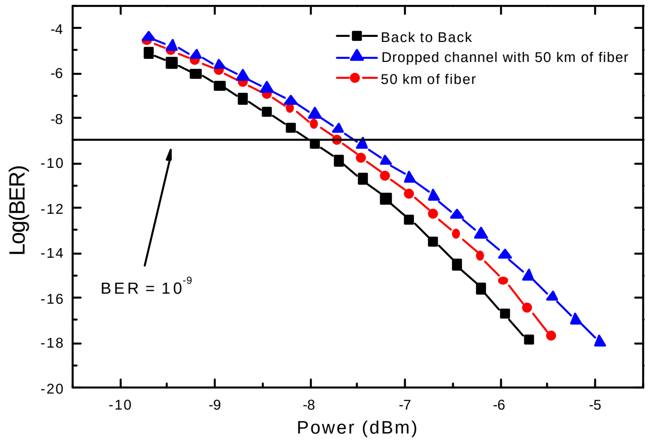

Figure 12 – Simulated BER performance for the dropped channel.

Figure 13 show the simulation detected eye diagram of the OADM dropped channel for a 10^{-9} BER.

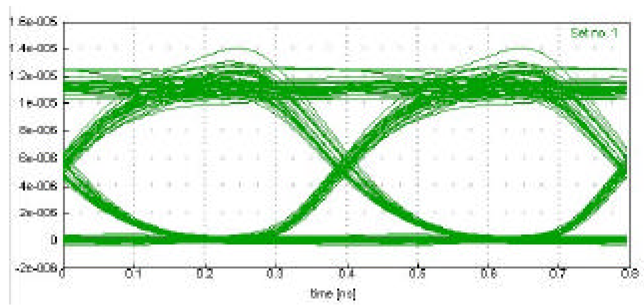
Figure 13 – Simulated eye diagram for the dropped channel.

These results show that the simulation transmission performance (BER characteristics) is well enough to predict the experimental results.

V. CONCLUSIONS

We have reported an OADM solution for DWDM systems using a FBG. The OADM performance was demonstrated in a 200 GHz, 3 channels WDM system, working at STM-16 bitrate. The power penalty due to the presence of the OADM in the network is small, therefore the cascading capacity of this OADM configuration is high, when compared with others OADM configurations [1]. The transparency of the OADM to the channel spacing and number of channels was demonstrated and the system performance degradations due to homodyne and heterodyne crosstalk induced by a FBG based OADM have been measured.

The simulation results for the experimental network agreed with the experimental results, validate the good performance of this OADM configuration and showed that the simulation can predict the measured BER characteristics.

The investigated OADM configuration is promising, due to its good spectral characteristics which results in low homodyne crosstalk, and consequently potential high cascability

VI. REFERENCES

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