# A Novel Architecture of an Optical Cross-connect Based on Tuneable Fibre Bragg Gratings and Optical Circulators

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**Abstract:** Optical networks have evolved to sustain the growing need for bandwidth in communication networks. *Wavelength switched networks* using *Dense Wavelength Division Multiplexing* (DWDM), are a solution to this problem. Development of these networks demands the use of *Optical Cross-connects* (OXCs), optical devices that are able to control the communications channels and route them correctly. In this paper, a novel switching architecture based on thermally tuneable Fibre Bragg Gratings (FBG) and optical circulators (OC) is demonstrated.

## 1. Introduction.

An unprecedented growth in data traffic and the need for network coverage over large distances has spurred the telecommunications industry to accept that optical networks are the only solution to build the backbone that will carry global data traffic whose volume has been growing to enormous rates that are not expected to slow down in the near future. Particularly, *All-Optical Networks* have been considered, in light of recent advances, the only technology capable of sustaining such growth and still provide *Quality of Service* (QoS). Therefore, new generation networks are designed as all optical to avoid the *electronics bottleneck*. That is, information is conveyed in the optical domain (without facing any electro-optical conversions) through the network until it reaches its final destination. The usage of DWDM (Dense Wavelength Division Multiplexing) as a physical layer networking mechanism, especially when signals are routed, switched and selected based on wavelength made optical cross-connects (OXCs) key components in such networks, allowing a more transparent, flexible and versatile network management.

Routing wavelengths requires the use of networks nodes that are wavelength selective, that is – *Wavelength Routers*. An optical cross-connect is a device that can be classified in this category. Various proposals have been made recently for OXC Architectures, namely Micro-Electro-Mechanical System (MEMS) – tuneable micro-mirrors placed in a silicon base, 'Bubble' switching – Gel/Oil based, Electrolographic - electroholographic matrix with ferro-electric crystals, and Fibre Bragg Grating (FBG) Based [1].

*Crosstalk* is the main performance evaluation parameter for these devices. Crosstalk can be of two types: *heterodyne crosstalk* derives from interferences of small power levels that appear outside the bandwidth of the channel, causing bit error rate increases when detecting the other channels (*interchannel crosstalk*); *homodyne crosstalk* results from interferences inside the channel's bandwidth (*intrachannel crosstalk*) [3],[4].

In this article a novel architecture of an OXC of $2\times2$ ports based on Fibre Bragg Gratings (FBGs) and three port optical circulators (OCs) is presented.

## 2. OXC architecture and experimental setup

The novel architecture presented is shown in Figure 1. Figure 1 a) and 1 b) show two equivalent representations of the OXC in a crossbar configuration and in a ring configuration, respectively. The structure of the OXC is composed of four optical circulator and thermally tuneable FBGs ($\lambda_M$, M=1,…, N) that are electronically controlled through Peltier devices, one for each pair of gratings. Thus, temperature is the parameter by which the required Bragg wavelength of the gratings is selected. Tuning the FBGs in pairs avoids a possible destructive interference between channels that could occur when different channels with the same wavelength are placed at adjacent input ports. The OXC is therefore a non-blocking structure with no restriction being imposed on the input wavelengths. The principle of operation of the OXC is the following: if wavelength $\lambda_i$ at input port 2 is to be routed to output port 1, for example, then a pair of FBGs is tuned to this wavelength routing the signal through the optical circulators to output port 1. If the FBGs are detuned from the input wavelengths these are routed directly to the same output port.

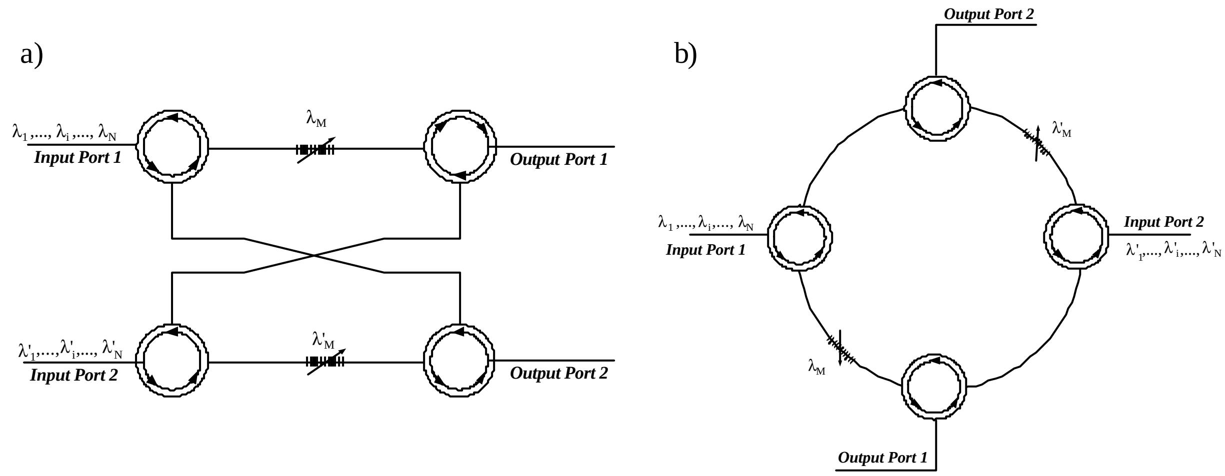


**Figure 1 – a) and b) The novel architecture of an $2 \times 2$ OXC**

An OXC based on the above mentioned architecture was developed using two uniform FBGs, with a wavelength of 1548.4 nm, and a FWHM of 0.2 nm and ~100% reflectivity period. These were fabricated through a phase mask technique with an UV KrF excimer laser.

The performance of the device was then assessed when accurately tuning the FBGs to route the input wavelength. In order to evaluate the performance more effectively optical laser sources where used. Tuneable lasers with high output power were applied to *input port* 1, $\lambda_2$ =1549.6 nm and $\lambda_3$ = 1550.4nm, and $\lambda_1$ = 1548.8 nm to *input port* 2. These channels are spaced according to the ITU recommendation for WDM with channel spacing of 100 GHz. The optical signals from these sources are depicted in Figure 2 a).

As a first step, the optical filters (FBGs) where detuned from any of the input wavelengths and the signals at the corresponding outputs where measured. The results of this test are shown in Figure 2 b).

As seen in the figure, the wavelength channels are properly sent directly to their correspondent outputs, i.e., Output 1 for channels 2 and 3; Output 2 for channel 1. The small peak at 1548.8 nm that appears in the signal at *output port* 1 is *heterodyne crosstalk* and has a power level of -45 dBm which is fairly negligible. *Insertion losses* are calculated with respect to the *input port* signals and are in this case 1.31 dB. These losses are originated in circulators and fibre splices and grating (optical filter) imperfections. The *heterodyne crosstalk isolation Level* is 30.72dB. The *homodyne crosstalk isolation level* is 30.89dB. These are very good isolation levels even when comparing this device with commercial ones.

In the next step, the optical filters (FBGs) where tuned to $\lambda_1$ = 1548.8 nm in order to switch channel 1 from *input port* 2 to *output port* 1. The results are in Figure 2 c).

As seen in this result, channel 1 is effectively switched to *output port* 1. Due to the increase in the reflections in optical filters and also an increase in the number of times a signal has to enter an optical circulator (thereby suffering from insertion losses) the total *insertion losses* in this case have increased to 4 dB. In *output port* 2 a -38.2 dBm crosstalk level is seen. The *homodyne* and *heterodyne crosstalk isolation levels* are, respectively 20.4 dB and 21.4 dB. These are good results and point to the good performance of this device.

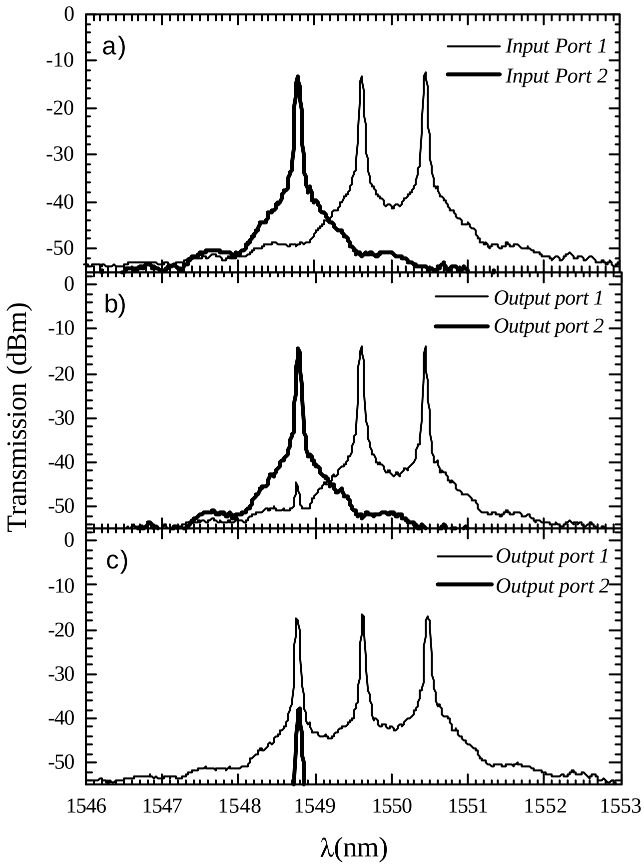


**Figure 2 - a) *Input port* signals ; b) *Output port* signals with optical filters detuned ; c) *Output ports* signals when Channel 1 is switched from *input port* 1 to *output port* 2.**

Another performance issue to be addressed is the tuning speed. The temperature control gives stable results but only slow tunability is achieved. This can be seen in the Figure 3 where the tuning and detuning speed of the optical filter (FBG) is seen.

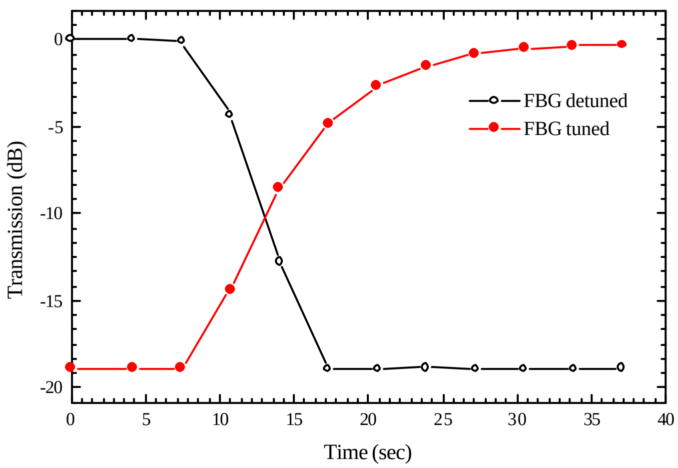


**Figure 3 - Tuning and detuning speed.**

When tuning, i.e., reaching a specified wavelength in order to reflect it, the achieved speed is around 10 seconds. But it should be noted that detection of the desired channels begins before the stable wavelength is reached. As the temperature of the grating increases, the central wavelength reflected by the grating changes until it reaches the desired wavelength. An important point to note is the fact that, once in a specific wavelength, the device maintains stability. The tuning and detuning speed can be improved if tuning through strain control using piezo-electric crystals is employed but at the cost of increased complexity since thermal stability still has to be maintained.

## 3. Conclusions.

A novel configuration of a non-blocking OXC was studied and demonstrated. The results obtained indicate that the OXC has a good performance with low homodyne and heterodyne crosstalk.

This configuration is totally transparent since there is no O/E conversion and has great flexibility in switching operation.

The demonstrated novel architecture of the OXC is totally scalable; this permits high cascading levels bringing this 2×2 structure to be generalized to *N*×*N* port configurations. This structure was implemented using only two tuneable FBGs, to demonstrate the configuration's concept, but there is the possibility of using 2×M FBGs, where M is the number of different wavelengths at the *input ports* of the OXC. It is a rearrangeably non-blocking configuration. This architecture has a patent pending.

## References.

[1] Y. W. Song, Z. Pan, D. Starodubov, V. Grubsky, E.Salik, S. A. Havstad, Y. Xie, A. E. Willner, J. Feinberg, *"All-Fibre WDM Optical Crossconnect Using Ultrastrong Widly Tunable FBGs"*, IEEE Photonics Technologhy Letters, VOL. 13, NO. 10, Outober 2001.

[2] Andreas Othonos, Kiriacos Kalli, *"Fiber Bragg Gratings – Fundamentals and Applications in Telecommunications and Sensing"*,Artech House, London, 1999.

[3] *P.S.André, J.L.Pinto, A.N. Pinto, T. Almeida,* "Performance Degradations due to crosstalk in Multiwavelength Optical Networks Using Optical Add Drop Multiplexers Based on Fiber Bragg Gratings", Revista do DETUA, Vol.3, no. 2, pp. 85-90, Setembro 2000.

[4] Xiangnong Wu, Xau Lu, Z. Ghassemlooy, Yixin Wang, *"Evaluation of Intraband Crosstalk in an FBG-OC-Based Optical Cross Connect"*, IEEE Photonics Technologhy Letters, VOL. 14, NO. 2, February 2002.