Optical Cross-Connect Architectures based on Fibre Bragg Gratings and Optical Circulators

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Abstract

We evaluate the performance of two different architectures of a 2×2 port optical cross-connects using tuneable Fibre Bragg Gratings and optical circulators. The impact of homodyne and heterodyne crosstalk in both configurations is studied. We demonstrate that the proposed cross-connects have the possibility of bidirectionality and are cascadable to N×N ports.

I. INTRODUCTION

Expanding Internet-based services are driving the need for evermore bandwidth in the new generation networks, consequently communications must evolve to sustain such a demand. All optical networks (AONs), based on the Dense Wavelength Division Multiplexing (DWDM) technologies, are very often considered to be the main candidate for constituting the backbone that will carry global data traffic in the near future.

In AONs, each connection (lightpath) is totally optical, and totally transparent, so a connection doesn’t need to be interrupted by any optical-electrical conversion. Optical Cross-connects (OXCs) are network elements that will play a key role in DWDM networks to provide more reconfiguration flexibility and network survivability. An OXC is an optical switch that can interconnect optical signals between multiple input and output ports, enabling switching and routing capabilities.

A fundamental difficulty of wavelength routing is the crosstalk from neighbouring inputs, which causes severe degradation in system performance. Depending on its origin, crosstalk, can be classified into two categories – Heterodyne and Homodyne Crosstalk. Heterodyne Crosstalk derives from interferences of small power levels that appear outside the bandwidth of the channel and interferes with the detection process. Homodyne Crosstalk results from interferences of leakage signals, inside the channel’s bandwidth, and is far more severe than Heterodyne Crosstalk [1].

Several architectures for OXCs based on Fibre Bragg Gratings (FBGs) and optical circulators (OCs) have been proposed [2-5]. The two configurations presented here are based on the nonswitched N-type building blocks configuration [6].

In this article we present first an OXC configuration (OXC1) based on two OCs and a FBG. Secondly, another OXC architecture (OXC2) based on four OCs and two FBGs is shown. The FBGs are thermally or piezoelectric transducer (PZT) controlled and act as wavelength selective filters that properly route the input signals to the desired output ports.

The experimental results are presented and the levels of homodyne and heterodyne crosstalk are assessed. The bidirectionality and cascadability of the architectures is also discussed.

Finally, a few concluding remarks about the developed structures and future work in this area are given.

II. OXC1 CONFIGURATION

A. OXC1 Experimental Setup

The first structure to be presented, OXC1 is shown in Fig. 1. This structure is patented [7] and is one of the recent developments in this area.

![Fig. 1 OXC1 Architecture](image)

The input signal, placed at Input 1, was obtained through optical spectral slicing of a LED’s emission spectra and is composed of three channels (λ₁, λ₂, and λ₃) of wavelengths 1549.9 nm, 1550.7 nm and 1551.5 nm, separated by 0.8 nm (100 GHz). The FBG λ₃ is used as a tuneable optical fibre and was fabricated with a central wavelength of 1550.7 nm, FWHM of 0.2 nm and near 100% reflectivity.

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B. OXC1 Results

When the FBG is stabilized at room temperature, the central wavelength is $\lambda_M = \lambda_2$, channel 2 at Input 1 is switched to Output 1. The other two channels ($\lambda_1$ and $\lambda_3$) are switched to Output 2.

In Fig. 2 it can be seen that the Crosstalk isolation level of channels $\lambda_1$ and $\lambda_3$ is -16.23 dB (Output 2). The small residual components centered in $\lambda_1$ and $\lambda_3$ are due mostly to residual reflections in the grating and circulators that give birth to Heterodyne Crosstalk.

As a second step in the analysis of this structure the FBG is detuned by temperature variation and the central wavelength is placed at an intermediate wavelength between $\lambda_2$ and $\lambda_3$ ($\lambda_M = 1551.1$ nm). In Fig. 3 we can see the power level of the signals in both outputs of the device. The three channels are switched to Output 2. In Output 1 the signal measured has a power level 10.53 dB below the one at Output 2. This signal is reflected from the grating and causes Homodyne Crosstalk.

due to fibre splices. Each signal incurs twice in these losses, which explains why the maximum power levels at the outputs are below the reference level by 2.4 dB.

The results presented in Fig. 2 and Fig. 3 are normalized with respect to the optical power level of Input 1.

Even though in this configuration only one FBG is used, there is a possibility of controlling more input channels by placing other FBGs with the one shown in this setup.

This configuration can also be transformed to allow switching in both directions (bidirectional cross-connect). This is depicted in Fig. 4 and it requires the addition of two four ports optical circulators and additional tuneable gratings in the new arm of the OXC1.

This structure has the additional advantage of being fully cascadable, i.e., a rearrangeable nonblocking N x N OXC1 can be constructed using basic 2 x 2 OXC1 blocks, based on Clöss [8] network architecture [2]. Fig 9 shows the required number of OCs and the required number, M, of FBGs in series per arm.
III. OXC2 CONFIGURATION

A. OXC2 Experimental Setup

The second structure tested, the OXC2, is built as depicted in Fig. 6. This structure is also patented [9].

![Fig. 6 OXC2 Architecture](image)

In order to evaluate the performance of this architecture laser sources where used: A tuneable laser was applied to Input 2 with wavelength ($\lambda_1$) centered at 1548.8 nm. At Input 1 a Fibre Ring Laser was used to create a signal with two wavelengths ($\lambda_2$ and $\lambda_3$) at 1549.6 nm and 1550.4 nm. The two FBGs $\lambda_M$ are tuned or detuned simultaneously and were fabricated with a central wavelength of 1549.6 nm, FWHM of 0.2 nm and near 100% reflectivity.

B. OXC2 Results

First of all, both FBGs were detuned from any of the input wavelengths and the signals at the corresponding outputs were measured. The results of this test are shown in Fig. 7.

![Fig. 7 Spectral response of the OXC2 when $\lambda_M$ is detuned](image)

The wavelength channels are properly sent directly to their correspondent outputs, i.e., Output 1 for channel 2 and 3; Output 2 for channel 1. The small peak, at 1548.8 nm, which appears in the signal from Output 1, is Heterodyne Crosstalk and has a power level of -45 dBm which is fairly negligible. Insertion Losses - originated in the circulators, fibre splices and FBGs imperfections - are calculated with respect to the input signals and are in this case 1.31 dB. The Heterodyne Crosstalk isolation level is 36.72 dB. These are very good isolation levels even when comparing this device with commercial ones.

In the next step, the FBGs where tuned to $\lambda_M = \lambda_1 = 1548.8$ nm in order to switch channel 1 from Input 2 to Output 1. The results are in Fig. 8.

As seen in this result, Channel 1 is effectively switched to Output 1. Due to the increase reflections in the optical filters and also an increase in the number of times a signal has to enter an optical circulator (thereby suffering from insertion losses), total insertion losses have increased 4 dB. In Output 2 a -38.2 dBm Crosstalk level is seen. The Homodyne Crosstalk isolation level is 20.40 dB. This is a very good result and points to the good performance of this device.

![Fig. 8 Spectral response of the OXC1 when $\lambda_M$ is tuned at $\lambda_1$](image)

As in the previous experience, additional FBGs can be used to control more optical channels at the same time.

This architecture has the possibility of being upgraded to ensure bidirectionality, i.e., allowing the same switching performance in both directions. This configuration can be seen in Fig. 9 and it demands only the addition of four port optical circulators and additional tuneable gratings in the crossing arms of the OXC2.

![Fig. 9 Architecture of a bidirectional OXC2](image)

The FBGs $\lambda_M$ are controlled at the same time allowing switching between Inputs 1 and 2, and Outputs 1 and 2, the FBGs $\lambda_P$ have also the same control scheme allowing the
switching between Inputs 3 and 4 to Outputs 3 and 4. This approach can be of great use to increase the flexibility in terms of wavelength distribution in a multiwavelength network.

It is also possible to build N×N OXC2 cross-connects, using basic 2×2 OXC2 blocks, based on Clös [8] or Beneš [10] network architectures [11]. These are totally non-blocking architectures, i.e., any channels present at the Inputs of the N×N OXC2 are properly routed to one of the outputs without the risk of having channels using the same wavelength routed to the same output. Fig 9 shows the required number of OCs and FBGs series for this structure.

![Graph showing the required number of OCs and FBGs series for OXC2 cross-connects](image)

**Fig. 10 – Number of required OCs and FBGs series in order to the OXC2 dimension**

### III. CONCLUSIONS

Two scalable tuneable OXCs (OXC1 and OXC2) based on FBGs and OCs have been studied and their performance evaluated.

The results of crosstalk obtained in OXC1 suffer from a penalty performance due to the wide spectral width of the sources used. Better performance would be obtained with narrow spectral width such as laser sources.

The worst crosstalk isolation levels obtained were 10.53 dB for OXC1 and 20.4 dB for OXC2. It should be noted that the use of gratings with an apodized refractive index profiles will reduce significantly the measured crosstalk levels.

The insertion losses are 2.4 dB in OXC1 and 2.14 dB in OXC2. Low insertion losses can be achieved using multi-port optical circulators.

Concerning cascadability both devices offers many possibilities. OXC1 can be expanded to an N×N OXC1 using the Clös architecture, and OXC2 is scalable to an N×N OXC2 using both Clös and Beneš networks.

The architectures have also possibility of being upgraded to ensure bidirectional behavior having the same performance in both directions.

The conjugation of these architectures with active devices such as Er doped fiber amplifiers, semiconductor optical amplifiers and FBGs with different spectral profiles can be of great use to increase the flexibility of wavelength distribution, for example by allowing wavelength conversion and reuse in the WDM network. This is the subject of ongoing work [12].

### V. REFERENCES


