Routing strategies of reconfigurable optical add drop multiplexer using different designing techniques

ARUNA RANI[a,*], MANJIT SINGH BHAMRAH[a,*], SANJEEV DEWRA[b,*]
[a]*Department of Electronics and Communication Engineering, Punjabi University, Patiala, 147001, Punjab, India*
[b]*Department of Electronics and Communication Engineering, Shaheed Bhagat Singh State Technical Campus, Ferozepur, 152002, Punjab, India*

This paper presents a comprehensive study of the architecture of reconfigurable optical add drop multiplexer (ROADM). Several architectures are introduced for ROADM based on optical switch (OSW), fiber Bragg grating-optical circulator (FBG-OC), digital switch and optical coupler. The performance of the designed architectures is compared by different low input transmission powers with channel spacing of 0.8 nm at 40 Gbps. The signal is transmitted successfully to a distance of 75 km with existing fiber nonlinearities and without using any dispersion compensating techniques or optical amplification. It is shown that better quality factor and least BER is achieved using digital switch and the worst case is found with the optical coupler. The digital switch has been selected as a promising switching element to build the basic reconfigurable optical add drop multiplexer.

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1. Introduction

As more numbers of optical channels are being established, proficient utilization of fiber bandwidth becomes critical. The ability to flexibly add and drop a group of channels or individual channels in a complex traffic pattern represents well organized network usage and cost saving. To understand the reconfigurable optical network topologies and carry the remote provisioning of the optical links, ROADM are the key solution of the recent optical communication services [1-3]. Due to the novel communication services like e-gaming and e-health, it is necessary to have a mechanism to remotely reconfigure the network topology. ROADM facilitates the network system evolution from a point-to-point transmission oriented structure to an all optical wavelength flexible dynamic network [4]. A ROADM is a node in an optical network where wavelengths can be flexibly routed among two or more multi-wavelength lines or “degrees” and local add/drop interfaces. Multi-degree reconfigurable optical add/drop multiplexers expand flexibility to the optical layer by adding dynamic reconfigurability of wavelengths. ROADM modules are simple to use as long as powerful features to make routing wavelengths as easy as routing circuits [5-6]. ROADMs can drastically reduce operating costs and increase revenue potential beyond traditional static optical designs by enabling dynamic optical transport solutions [7-8].

Sorin Tibuleac and Mark filer [9] demonstrated the ROADM induced transmission impairments that are frequent to multiple WSS technologies employed in commercial ROADM networks. The insertion loss of the ROADM is essentially dependent on the node design. Because of the narrow channel spacing of the DWDM channels the loss of wavelength selective switches also increases. The power setting and quicker wavelength power monitoring may be achieved on some WSS technologies, which can release new avenues within the future for decrease of power variations in DWDM networks. T. A. Strasser and J. L. Wagener [10] reviewed the functions of WSS optical switching technology to ROADM networking applications together with the technology and have trends driving the development of WSS and ROADM deployments in present networks. Liming Zheng [11] compared many design strategies of ROADM and introduced the planning and realization of ROADM derived from FBG and OSW. The design of FBG-OSW composed OSW and FBG collimator was proposed that was the integration package of FBGs and collimator. The performance of ROADM can be optimized from the filter characteristics of FBGs and the selectivity of OSW. Qirui Huang et al. [12] proposed a simple, cheap and scalable ROADM supported parallel configuration with MZ-FBG modules having 1×2 OSWs and combiners. The planned ROADM with four stage parallel configuration was investigated and characterized to indicate its performance. An Vu Tran [13] proposed the two novel strictly non-blocking reconfigurable multichannel optical add drop multiplexers (RM-OADMs) with optical circulators and fiber Bragg gratings. The new structures considerably attain good crosstalk performance, decrease insertion loss and component count using eight port optical circulators.

S. Fazel et al. [14] demonstrated two architectures to propose a ROADM node with nodal degree of three. The extinction ratio and side band suppression ratio of both architectures was compared. It was demonstrated that the total benefit about the performance will be 4.5 dB improved by using WSS as both multiplexer and demultiplexer rather than using a splitter as demultiplexer for the ROADM nodes with degree of 3 or less.

The analysis and comparison of various ROADM designs provides a practical approaching to the optical communication network designers to decide an appropriate architecture. Reconfigurable optical add/ drop multiplexers developed with various plans and innovations are rapidly going to be accessible in the market. Unfortunately, the most recent ROADM designs are either affected by high manufacturing costs or high insertion losses that prevent their fast exploitation in the network. In this paper, the ROADM subsystem architecture that combines the prevalent characteristics of the current ROADM designs is proposed.

The rest of the paper is structured as follows. In Section II, the different architectures of ROADMs are addressed. Results & discussion are investigated in Section III. Paper concludes in Section IV.

2. Designing techniques of ROADM

ROADMs are the fundamental component in building the next generation, dynamically reconfigurable optical networks. ROADMs alter dynamic add/drop or specific tolerate of individual channels or cluster of channels at network nodes while not the necessity of optical-electrical-optical conversions. Hence, it influences optical performance, configuration flexibility and cost. The architecture of the ROADM based on FBG-OC, Optical switch, digital switch and optical coupler are analyzed.

2.1. Architecture of the ROADM based on FBG and OC

In the proposed network, the channels wavelength is chosen between 193.1 THz-193.8 THz with channel spacing of 100 GHz. When routing by OSW, input signals are sent into a FBG. Since the FBG has wavelength selection ability, only one desired wavelength will be reflected back and emerge at drop port through the circulator. Other remaining wavelength through the FBG will be multiplexed with added signal by circulator and continue to transmit.

The fundamental principle of FBG is Fresnel reflection, where light traveling between media of different refractive indices may both reflect and refract at the interface. The refractive index will exchange over a defined length. The reflected wavelength is called the Bragg wavelength.

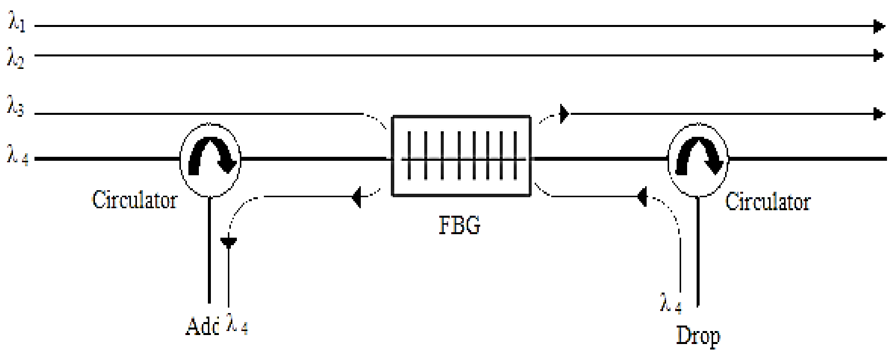

Fig. 1. Structure of the ROADM based on FBGs and OC

The ROADM consist of OCs and FBGs of wavelengths 193.5 THz, 193.6 THz, 193.7 THz, 193.8 THz corresponding to channels one, two, three and four of the input signal, respectively. The bragg wavelength of FBG is planned to match the input channel. The channel corresponding to the FBG connected between ports of each OC goes through the device together with other through channels. The channel is dropped through and another channel at the same wavelength can be added. The tuned wavelength is bragg wavelength which is reflected from T-FBG and can be written as [15].

$$\lambda_B = 2.\bar{\cap}.\Lambda \quad (1)$$

In equation (1), $\bar{\cap}$ is effective index of grating, λ_B is bragg wavelength and Λ is grating period. The effective refractive index quantifies the velocity of propagating light as compared to its velocity in vacuum. n_{eff} depends not only on the wavelength but also on the mode (for multimode waveguides) in which the light signal propagates. For this cause, it is also called modal index. The bragg wavelength is 99.9 % reflected from the T-FBG by optimized the parameters such as apodization, grating length and effective index of T-FBG.

The reflectivity of optical signal in T-FBG is function of detuning length of grating and effective index of grating as shown in equation (2).

$$R_{FBG} = r(w) = \frac{i.k.\sin(q.L_g)}{q.\cos(q.L_g) - i.\delta.\sin(q.L_g)} \quad (2)$$

$$\frac{2\pi}{\lambda_o} - \frac{2\pi}{\lambda_B} \quad (3)$$

$$K = \frac{\pi . n_g . \Gamma}{\lambda_B} \quad (4)$$

In equation (2), L_g is grating length of T-FBG. In equation (4), n_g is effective index of grating, k is coupling coefficient, λ_B is bragg wavelength and Γ is confinement factor. The reflectivity of optical signal is varied from T-FBG, when there is change in length of grating, effective index of grating and apodization. Because the reflectivity of optical signal is function of these parameters as written in equation (2). The system performance is increased if the reflection of signal from FBG is optimized because crosstalk in system is minimized.

The FBG-OC based ROADM is promising due to their low crosstalk, temperature and polarization insensitivity. Additionally, FBG-OC based ROADM does not cause bandwidth narrowing once optical signals bypass through several OADM nodes. However, this FBG-OC based ROADM still suffer from high component count and high insertion loss owing to the utilization of the many circulators and a combination of mux–demux.

2.2. Architecture of the ROADM based on optical switches

An optical switch enables signal in the optical fibers or integrated optical circuits to be selectively switched from one circuit to another. There is no need for a lot of expensive high speed electronics, optical switching should be cheaper. Optical switching technology is still in its infancy stage. Optical switches can be used as fundamental arrangement for network nodes to provide optical circuit or packet switching. The working principle of most optical switches is the π-π phase shift. Optical switches mostly work on the principle of interference of light between two paths or optical modes. Switching light from on to off (modulation) involves changing this interference from constructive to destructive. Similarly, switching light from one path (say path A) to another (path B) involves changing from constructive interference in path A and destructive in path B to vice versa. The way to effect this change of interference is to make a π-π phase change by somehow controlling the refractive index of the material in part of our device.

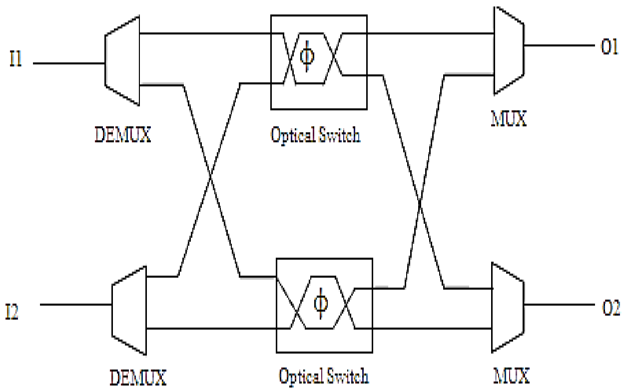

Fig. 2. Structure of the ROADM based on Optical Switches

The optical switch performance parameters are the high isolation, fast switching speed, low insertion loss, reliability and polarization insensitive. The nonlinear loop mirror light switch, Mach-Zehnder interferometer type optical switch and light control switch is mainly used in ultra-high speed optical communication. Light control switch are not only used for ultra-fast switching exchange, other than also for all optical signal regeneration and ultrafast wavelength conversion shows potential all optical switching technology.

2.3. Architecture of the ROADM based on digital switches

A digital switch is a component for handling digital signals. The main function of these switches is to manage digital signals generated or passed through a telephone exchange and then forward it to the telephone company's back-end network. The digital optical switch routes the optical signals according to the control signal at input port 1 and 2 to the two output ports. The optical signal at input 1 is passed to output 1 and the optical signal at input 2 is passed to output 2, if the control signal is 0. If the control signal is 1, then the optical signal at input 2 is passed to output 1 and the optical signal at input 1 is passed to output 2. The working behavior of this component is similar to the optical switch component. When the control signal is 0, internally phase shift is set to Π, and when the control signal is 1, phase shift is set at 0.

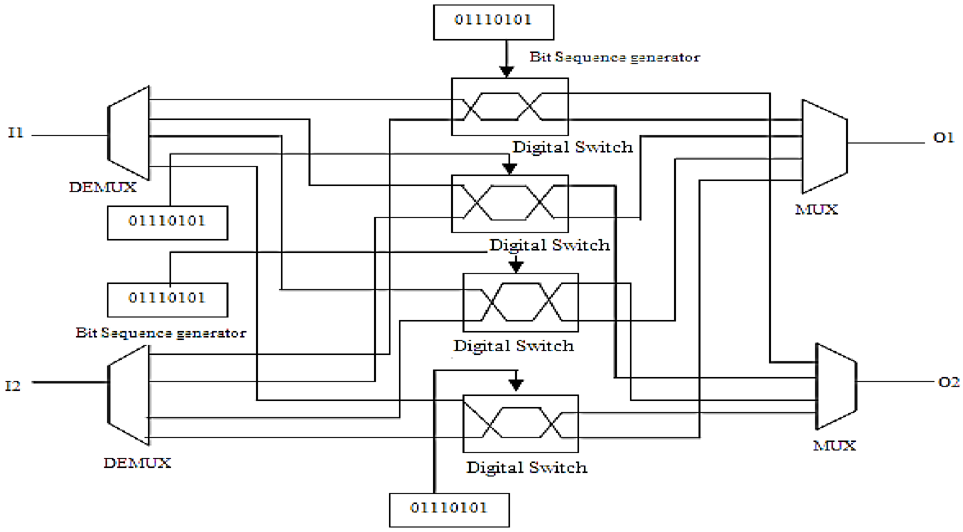

Fig. 3. Structure of the ROADM based on digital Switches

The communication between the subscribers of a telephone company is established with the help of digital switching. Digital switches can be of different types based on the number of lines they handle and the included features. Digital switches are much faster in performance compared to analog switches.

2.4. Architecture of the ROADM based on optical coupler

In order to allow the transmission of light waves in multiple paths, a fiber optic coupler is capable of connecting one or more fiber ends. The device is capable of dividing a single input into two or more outputs and also combining two or more inputs into a single output.

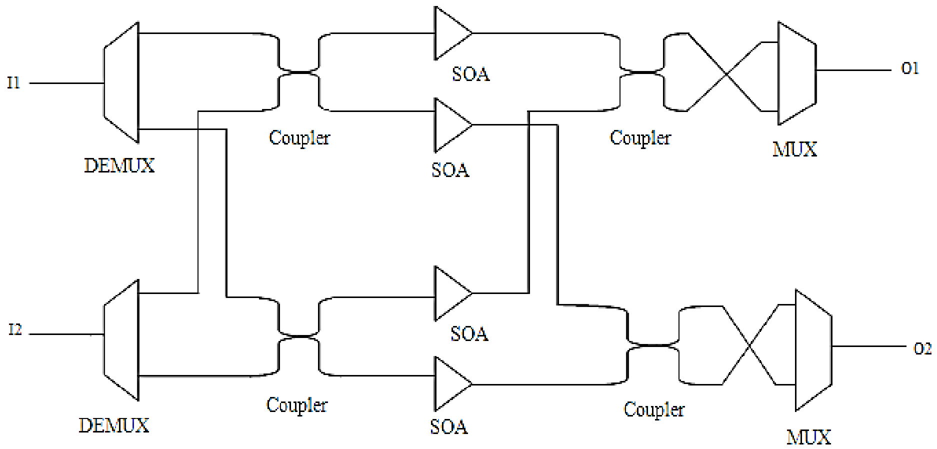

Fig. 4. Structure of the ROADM based on optical couplers

The incoming input optical signal splits into two beams of light using a 3-dB coupler. Then beams of light are travelled through two different arms of the same length. Another 3-dB coupler is used to merge the optical signal at output port of the switch and then again splits the optical signal. The refractive index of arm is increased, when the optical signal is communicated through the one arm of interferometric switch due to heating effects in the switch. Due to heating effects in the switch, phase difference occurred between the optical signals in one arm of interferometer. The output of switch may be destructive or constructive. Light entering an input fiber can come into sight at one or more outputs and its power distribution potentially depending on the polarization and wavelength. Couplers can be fabricated in different ways such as by thermally fusing fibers so that their cores get into intimate contact. There are certain physical restrictions on the performance of the coupler if all involved fibers are single mode. It is not possible to combine two or more inputs of the same optical frequency without significant excess losses into one single polarization output. There are couplers that can combine two inputs at different wavelengths into one output without exhibiting major losses. Though, such a constraint does not take place for different input wavelengths.

3. Results and discussion

The performance of the different architectures of ROADM is evaluated in terms of Q-factor, BER, optical signal to noise ratio (OSNR) and received optical power. The quality factor is a consideration that is used to determine the quality of signal for formatting the BER. The Q-factor of a signal is defined as

$$Q = \frac{\sqrt{I(1)} - \sqrt{I(0)}}{\sqrt{N_{tot}(1)} + \sqrt{N_{tot}(0)}} \qquad (5)$$

Where I(1), I(0) are the optical signal and and $N_{tot}(1)$, $N_{tot}(0)$ are total noise for a mean signal level at "1" and "0". If Q-factor is high, then the quality of optical signal is better. The BER can be obtained from the Q-factor and is the ratio of the number of errors received in a bit at the receiver side and the number of bits transmitted:

$$BER = \frac{1}{2}\operatorname{erfc}\left(\frac{Q}{\sqrt{2}}\right) = \frac{1}{\sqrt{2\pi}\,Q}\exp\left(-\frac{Q^2}{\sqrt{2}}\right) \qquad (6)$$

Hence, the higher value of the Q-factor, better the BER.

Fig. 5 shows the variation of Q-factor with input transmission power for the different designing components of ROADM. It is evident that Q-factor increases with increase in input transmission power from 0 to -12 dBm. It is found that Q-factor achieved is 6.48, 5.23, 5.11 and 4.96 for digital switch, FBG-OC, optical switch and optical coupler respectively having input transmission power of -12 dBm at transmission distance of 75 km.

Fig. 6 shows the bit error rate vs. input signal power for different designing components of ROADM. At -12 dBm signal input power, BER achieved for digital switch is 3.16e-09, FBG-OC is 1.16e-09, optical switch is 1.16e-08 and optical coupler is 1.16e-07. It is observed that BER decreases with increase in input transmission power from 0 to -12 dBm due to fiber non-linearity, dispersion and loss in the power of signal.

Fig. 7 depicts the deviation of OSNR vs. input signal power for different designing components of ROADM. It is analyzed that when the input signal power varies from to 0 to -12 dBm, OSNR increases.

The plot of received optical power vs. input signal power for different designing components of ROADM is shown in Fig. 8. The received optical power increases as the input signal power varies from 0 to -12 dBm. The variation in output power for different designing components is -30.12 dBm to -18.21 dBm for digital switch, -29.78 dBm to -17.23 dBm for FBG-OC, -27.34 dBm to -15.36 dBm for optical switch and -28.78 dBm to -16.23 dBm for optical coupler.

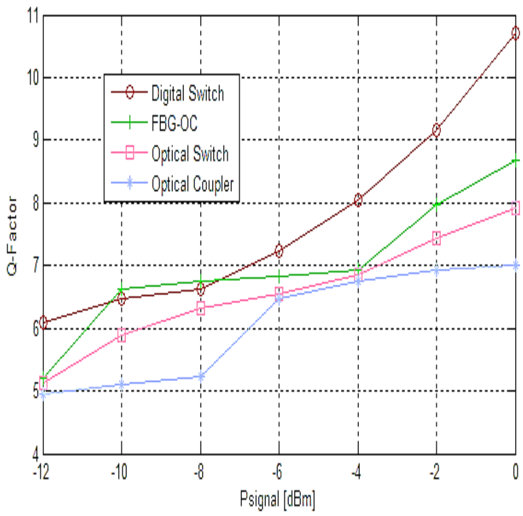

Fig. 5. Q-factor vs. input signal power

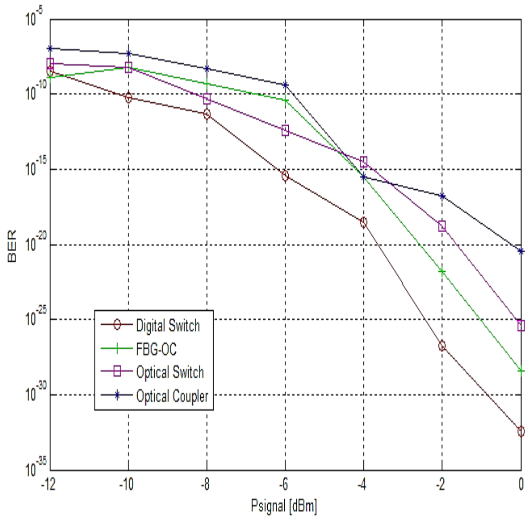

Fig. 6. BER vs. input signal power

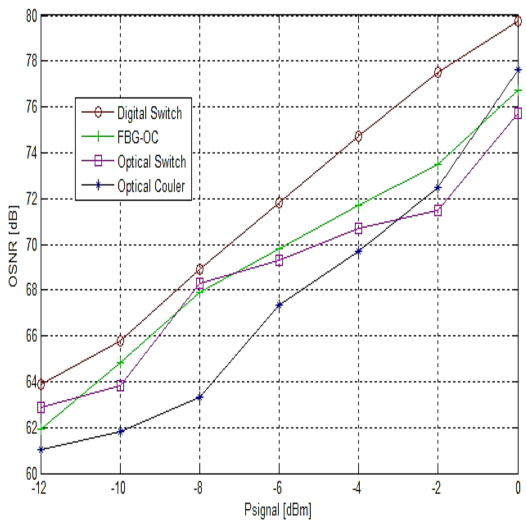

Fig. 7. OSNR vs. input signal power

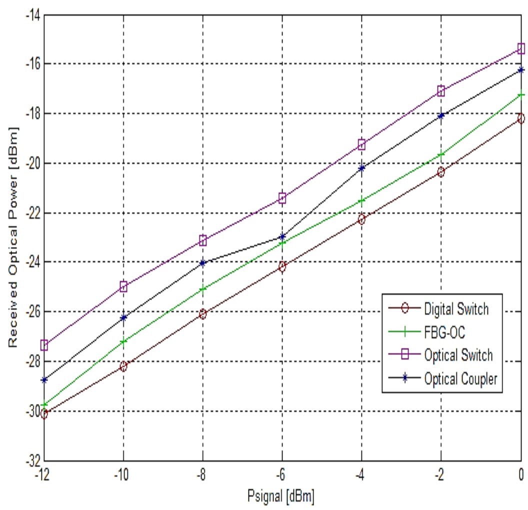

Fig. 8. Received optical power vs. input signal power

4. Conclusion

ROADM plays a significant function to provide the remotely reconfigurable optical networks in current optical communication networks. This paper compared the ROADM architectures from different viewpoints. The FBG-OC based ROADM is promising due to their low crosstalk, temperature and polarization insensitivity. However, this FBG-OC based ROADM still go through from high component count and high insertion loss owing to the utilization of the many circulators and a combination of multiplexer–demultiplexer. The architecture of the ROADM based on digital switch is found to be beneficial as the key establishment in today's communications.

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*Corresponding author: arunarani70@gmail.com,
manjitsingh_manjit@rediffmail.com
sanjeev_dewra@yahoo.com