

# Optical signal buffering using fiber Bragg gratings in all optical networks

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All Optical Networks (AONs) are considered the future scenario for core networks. One of the major problems in AON is resources contention. One of the ways to solve this is buffering. This paper demonstrates a tunable optical buffer using an array of uniform fiber Bragg gratings (FBGs) and tunable wavelength converters (WCs). An enhancement to the system is achieved using chirped FBG to compensate dispersion and erbium doped fiber amplifier (EDFA) to overcome attenuation of the system. The simulation shows improvement in many parameters such as quality factor and bit error rate (BER). Also, a better network utilization and shorter fiber delay line (FDL) by 50% are achieved.

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**Keywords:** Optical buffer, Fiber delay line (FDL), Fiber Bragg grating (FBG), Dispersion compensator and Erbium doped fiber amplifier (EDFA)

## 1. Introduction

Optical networks have become an important part of the global telecommunication infrastructure due to the merits of the optical fiber, which is the only medium capable to move data at multiGbps commercially [1]. Basically, optical networks provide two functions: transmission and switching. The signal is transmitted through the optical fiber, and the optical signal is switched by cross-connects [2]. Driven by the Internet, the demand for bandwidth is constantly increasing. The present-day transmission technologies are sufficient to meet the demand for bandwidth. However, electronic switches in present-day are significant bottlenecks that limit the bandwidth [3]. To eliminate this bottleneck, all-optical networks are the future telecommunication networks [4]. Contention arises when packets from different sources arrive at one node within the same time slot and same wavelength and need to be routed to the same destination. Packet contention can be solved via buffering [5 - 10].

In this paper, a simple tunable optical buffer is proposed and compared to traditional optical buffers [6, 7] showing a great enhancement in network performance. This paper is organized as follows: Section 2 presents the optical contention scenarios and traditional optical buffers in today's networks. Section 3 is devoted to the proposed optical buffer system. Enhancements obtained by the proposed optical buffer system are shown in Sec. 4, where all simulations are carried out through Optisystem. This is followed by the main conclusions in Sec. 5.

## 2. Traditional optical buffer model

Contention appears when two input signals simultaneously attempt switching through the same output port at the same time and the same wavelength. When this occurs, in electrical based networks, contention resolution is provided via memory buffering. Lower priority traffic remains buffered until higher priority transmissions are complete. Memory buffering facilitates store-and-forward switching, thereby preventing the loss of information as it traverses the network. The alternative to memory buffering is traffic rejection, or the drop of packets at the congested node. In optical networks, the concept of memory buffering is yet unrealized. Optical delay lines currently hold the most promise for fulfilling the optical buffering need [10].

Different researchers used FBG to make a fiber delay line (FDL) with fixed delay values such as the work of C. Caucheteur et al [11] and K. Qian et al. [12]. This paper is extending the use of FBG in FDL achieving more flexibility to the system through a variable and controlled delay time. Also, it enhances the dispersion and attenuation of the signal transmitted in the fiber.

Fig. 1 shows the proposed simple fiber delay line (FDL) system. The delay lines consist of fibers with different lengths that are tuned to deliver the optical signal after specific delay intervals. In the next section, a tunable optical buffering is implemented to solve the disadvantages of traditional methods.

### 3. Tunable buffer with three precision values

The proposed system shows a new high accurate optical buffer with three precision values. Fig. 2 shows the

sections of the tunable buffer starting with the decision unit which is responsible for mapping delay time to the wavelength domain. This delayed wavelength,  $\lambda_{\text{delay}}$ , is related to the Bragg wavelength of the cascaded FBGs.

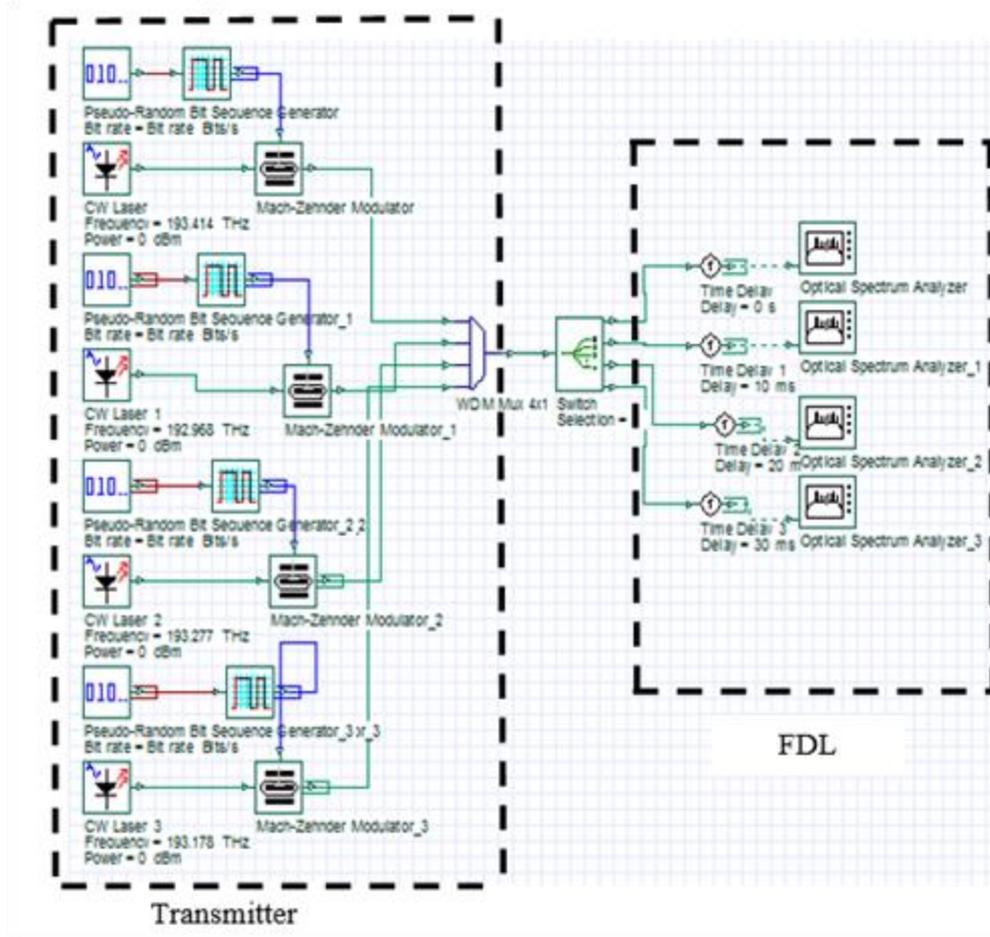


Fig. 1. Transmitter section of single-stage feed-forward 4x4 optical buffer structure

The mapped (required) delay time,  $T_i$ , can directly calculated from

$$T_i = 2 (nL_i/c) \quad (1)$$

where  $n$  is the core refractive index ( $= 1.5$ ),  $c$  is the free space speed of light and  $L_i$  is the fiber length to FBG1.

Three FBG cascaded arrays are used to get the required accurate delay in the proposed system. The first array is attached to port 3 in OC1 and has a gap distance of 100 m between each FBG resulting in a delay of 1  $\mu\text{s}$ , starting from FBG1 to FBG10. The same is done in FBG arrays 2 and 3 with distances 10 and 1 m, respectively, resulting in a delay of 0.1  $\mu\text{s}$  and 0.01  $\mu\text{s}$ , respectively.

Based on the needed delay from a decision unit, an input wavelength is converted to a specific wavelength from WC1 with respect to the corresponding FBG reflector needed. It is then forwarded to the circulator port

1 which forwards it to port 2. Then, the signal is reflected from the specific required FBG which is distributed by 100 m back to the circulator after the needed delay. The same scenario is repeated with WC2 and WC3 for more precision for exact delay values. At the end, WC4 is added to reverse the delayed wavelength to its original input wavelength.

As an example for the system, as shown in Fig. 2 (a), if one needs a delay of 7.54  $\mu\text{s}$ , the input decision control unit will make WC1 convert the wavelength to  $\lambda_8$  which is 700 m away. So, the delay based on Eq. (1) will be 7  $\mu\text{s}$ . Then, the control unit will adjust WC2 to  $\lambda_6$  and WC3 to  $\lambda_5$  which will make an exact delay for the signal by 7.54  $\mu\text{s}$ . Then, WC4 will convert the signal to its original wavelength after the delay. One have to keep in mind that,  $\lambda_1$  is the signal with distance 0 m. This proposed system can give a delay of 3 decimal precision values in  $\mu\text{s}$ .

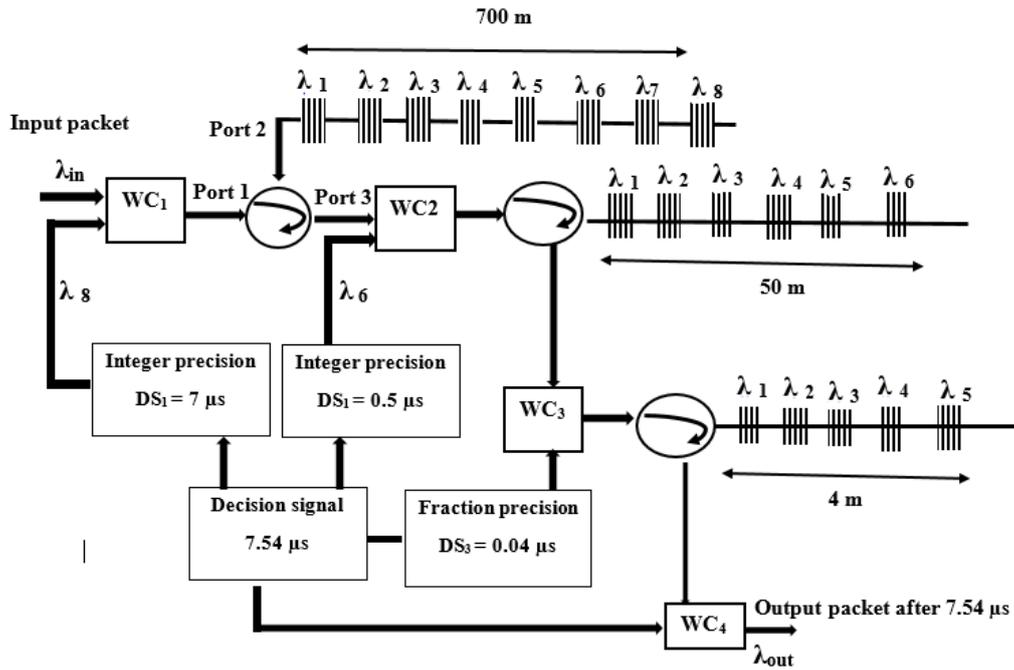


Fig. 2. (a) Three precision proposed optical buffer system

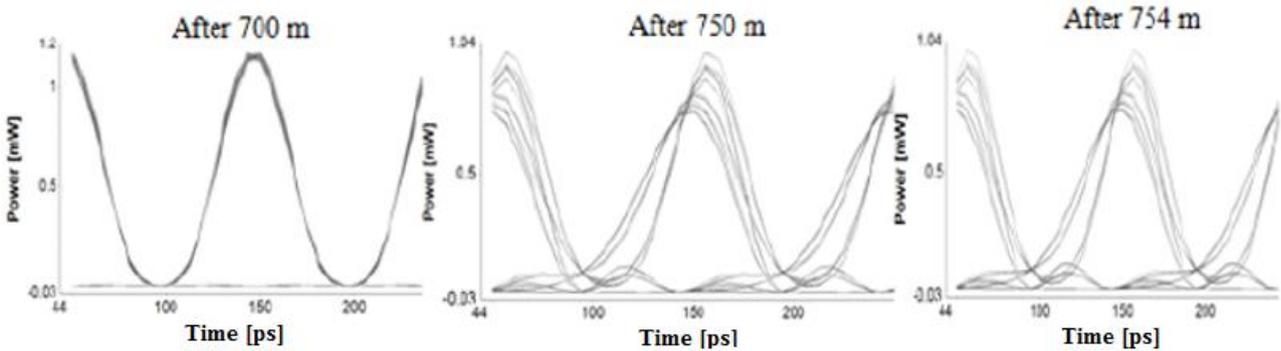


Fig. 2. (b) The eye diagram for the proposed system

The eye diagram using Optisym simulator is shown in Fig. 2 (b) to illustrate the signal at different parts in the system.

Although this proposed system has many advantages and can give an accurate optical buffer system with even reduced fiber cable length, it has some problems; mainly dispersion and attenuation. In the next section, a proposed modification is introduced to solve both problems.

#### 4. Enhanced tunable optical buffer with dispersion compensator and EDFA

The proposed system includes a chirped FBG instead of uniform FBG to solve the dispersion problem. It also includes an EDFA to compensate the attenuation. This is shown in Fig. 3.

Fig. 3 shows one branch of the system after the usage of chirped FBG and EDFA. The proposed system achieved better dispersion and attenuation. The parameters used in system simulation are summarized in Table 1.

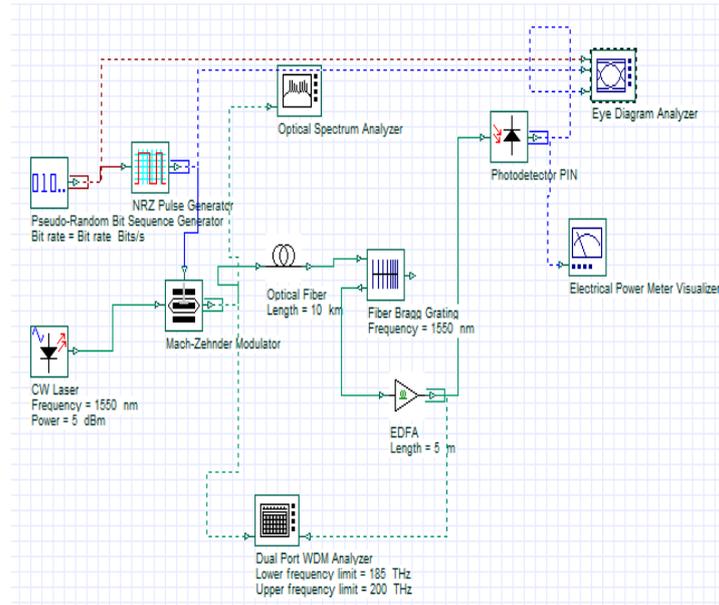


Fig. 3. Enhancement tunable optical buffer with dispersion compensator and EDFA

Table 1. Simulation parameters

Continuous wave laser wavelength	1550 nm
Input power	5 dBm
Mach-Zehnder modulator extinction ratio	30 dB
Bragg wavelength	1550 nm
Effective index	1.45
Length of chirped FBG	2 mm
Chirp function	Square root
Square root parameter	0.0001 $\mu\text{m}$

In this simulation, a continuouswave (CW) laser with wavelength of 1550 nm and output power of 5 dBm is used. The CW laser is externally modulated at 10 Gbps with a NRZ pseudorandom binary sequence in a Mach-Zehndermodulator. An EDFA is used with gain of 6 dB.

#### 4.1. Analysis of optical buffer system with dispersion compensator and EDFA

Figs. 4 and 5 represent the eye diagrams of the optical buffer FDL system before using EDFA and dispersion compensator, and after using EDFA and dispersion compensator, respectively. Table 2 shows the different time delays at which eye diagram is illustrated in Figs. 4 and 5. The huge difference results in a great decrease in BER and a remarkable increase in the Q-factor. Table 3 summarizes the system performance enhancement when a dispersion compensator and EDFA are employed.

Table 2. Time delay values corresponding to eye diagrams

Eye diagram	A	B	C	D	E	F
Delay, $\mu\text{s}$	50	100	150	200	250	300

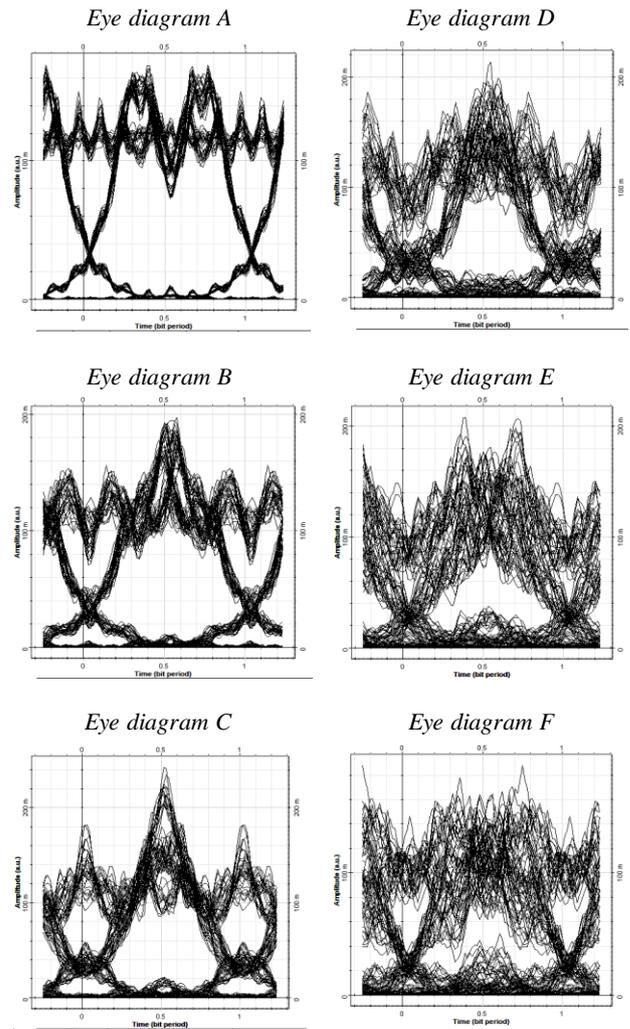


Fig. 4. Eye diagram of the buffering FDL system before using the dispersion compensator and EDFA

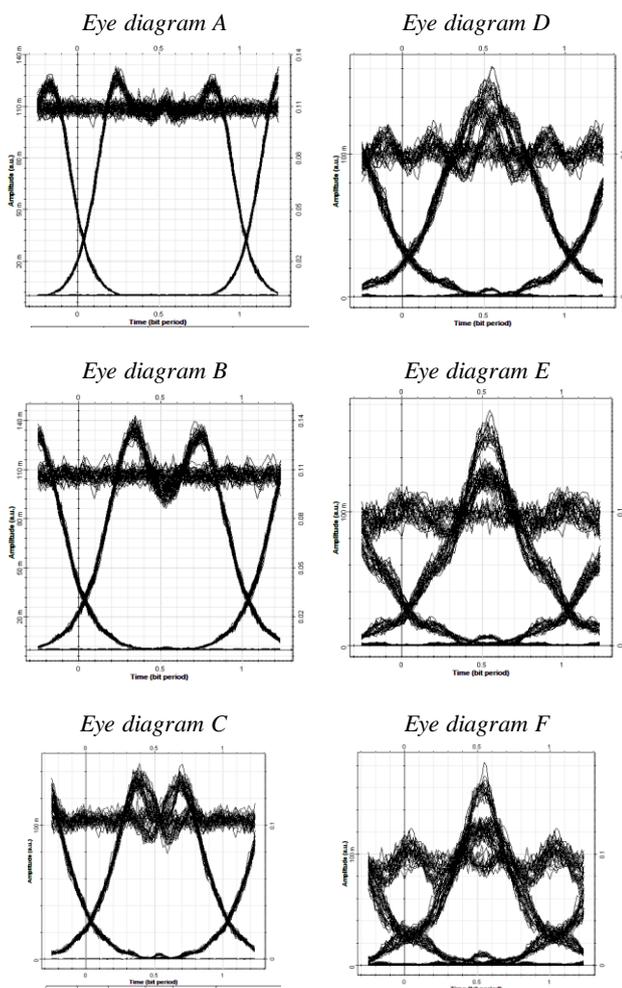


Fig. 5. Eye diagram of the buffering FDL system after using the dispersion compensator and EDFA

Table 3. Performance enhancement when using a dispersion compensator and EDFA at 300  $\mu$ s delay

Eye diagram	BER	Maximum Q-factor	FDL length (km)	Delay ( $\mu$ s)
Fig. 4 (without EDFA and compensator)	$2 \times 10^{-4}$	3.50835	60	300
Fig. 5 (with EDFA and compensator)	$1.8 \times 10^{-26}$	10.5606	30	300

## 5. Conclusion

A selectable accurate three precision optical buffer FDL system is proposed using FBGs and WCs. A better network utilization and shorter FDL are achieved. Accurate and variable time delay is accomplished with a 50% reduction in the FDL lengths. System BER and Q-factor are greatly enhanced when a dispersion compensator and EDFA are employed.

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