Performance evaluation of the UDWDM-PON with 10 Gbps bit rate using FBG based dispersion compensation

UMESH TIWARI[a], THAN SINGH SAINI[a*], CHHAVI SAINI[b], MANISH BHARADWAJ[c]
[a]*CSIR-Central Scientific Instruments Organisation, Sector-30C, Chandigarh-160 030, India*
[b]*Department of ECE, National Institute of Technical Teachers Training & Research, Chandigarh-160 030, India*
[c]*Council of Scientific and Industrial Research-HRDG, New Delhi-110 012, India*

The maximum span length of 16-channel ultra-dense wavelength division multiplexed passive optical network system has been reported with efficient dispersion compensation using the chirped fiber Bragg grating. The quality factor, bit error rate and span length under two different modulation schemes have been simulated for the designed network. Simulated results reveal that the fiber Bragg grating based DEMUX gives better performance at the data rate of 10 Gbps.

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1. Introduction

The chromatic dispersion is one of the major issues in the wavelength division multiplexing passive optical network (WDM-PON) because it limits the length of the network in long haul optical communication systems. WDM-PON supports many users at a time for the data transmission but as the spacing between the channels is reduced, the capacity of the system increases simultaneously the quality factor decreases due to the less space between two users. When the data transmission rate keeps increasing the performance of the WDM-PON is limited by the chromatic dispersion and various non-linear optical effects such as self-phase modulation (SPM), cross-phase modulation (XPM), and four wave mixing (FWM) arises in the fiber optic network. Therefore, in order to acquire higher data transmission rate at long-span light-wave system, the chromatic dispersion must be compensated. Many compensation techniques have been demonstrated exhibiting the different and often complimentary properties [1-4]. In the passive optical network (PON) the active devices are removed from the network to advance the reliability of the optical network and to minimize the maintenance and operational cost of the system [5]. Further the capacity of the existing passive optical network is increased by employing the concept of wavelength division multiplexing (WDM) to the PONs.

The chromatic dispersion at 1550 nm wavelength window is the key issue for high speed and long distance transmission. By choosing appropriate dispersion compensation technique along with suitable parameters, the optimum and effective WDM-PON system can be implement to improve the performance of the long-haul communication systems. Therefore, researchers are using various dispersion compensation techniques including optical phase conjugation, electronic signal processing, dispersion compensation fiber (DCF) modules and the fiber Bragg grating (FBG) based devices to compensate the dispersion effect in the communication systems. At present the dispersion compensation fiber (DCF) and fiber Bragg gratings (FBG) are more popular dispersion compensator than other schemes. The performance of the DWDM-PON at 100 GHz channel spacing with return-to-zero (RZ) and non-return-to-zero (NRZ) modulation formats has been simulated using 20 Km long dispersion compensating fiber (DCF) with dispersion coefficient of -83.75 ps/nm/Km and an Er-doped fiber amplifier (EDFA) with gain of 35 dB [6]. A 40 Gbps long haul DWDM system with a high data rate using various modulation formats like carrier-suppressed return-to- zero (CSRZ), duobinary return-to-zero (DRZ) and modified duobinary return-to-zero (MDRZ) have been simulated [7]. Chen et al. [8] demonstrated the DCF module applied in 40 Gbps WDM systems. Although the DCFs are widely used as the dispersion compensator device but they have some limitations like high insertion loss and low tolerance of high optical power.

It has been observed that the fiber Bragg grating (FBG) based devices can provide better solutions in modern communication system in dispersion compensation due to its low insertion loss, small footprint, polarization insensitive and negligible non-linear effects [3, 9]. In these devices, regulating group velocity dispersion compensation can be accomplished by shifting the grating chirp using either the temperature gradient [10 – 13] or strain gradient [14] across the length of the FBG. Thermally chirped FBGs exploit mostly the thermo-optic effect of the optical fiber, with the sensitivity of free FBG of 11.1pm/K, for adjustable group velocity dispersion [11, 12].

In order to alteration the chirp of the FBG thermally, an integrated on-fiber thin-film heater [13], ten peltier elements [15], and thin-film heaters with 32 sections [16, 17] have been employed; however, these structures are relatively complex. The center wavelengths of these devices are generally detuned from the specific wavelengths when changing their group velocity dispersion. Gupta et al. [18] projected a chirped fiber Bragg grating based de-multiplexer for ultra-dense WDM (UDWDM) PON to obtain 2.5 Gbps. UDWDM schemes greatly increases the capacity of the network and needed to meet the ever-increasing demand for high capacity optical links. Yusoff et al. [19] demonstrated the signal performance after propagating through a 90 Km optical fiber at the rate of 10 Gbps using a fiber Bragg grating as the chromatic dispersion compensator.

In this paper, we have reported the performance of WDM DEMUX for 16 channels UDWDM-PON and compared its performance for NRZ and DRZ modulation formats in terms of the quality factor and span-length of the fiber optic communication network. A chirped fiber Bragg grating is used in the link to minimize the effect of chromatic dispersion at 1550 nm wavelength. The simulated results indicate that the chirped FBG based DEMUX offers better performance in UDWDMPON at the data rate of 10 Gbps. Introducing the chirped fiber Bragg grating improves the quality factor along with the span-length of the optical fiber communication network.

2. Dispersion compensation through FBG

The fiber Bragg grating (FBG) is a passive optical device in which the refractive index of the core varies periodically through the length of the grating. In principle, the FBGs are used to reflect a particular wavelength, called Bragg wavelength (λ_B) and transmit remaining wavelengths according to the Bragg condition as represented byEq.1:

$$\lambda_B = 2n_{eff}\,\Lambda \tag{1}$$

where λ_B= reflected wavelength (called Bragg wavelength), Λ= grating period, n_{eff}= effective refractive index of core[20].Chirped FBG scheme is a new technique to compensate the chromatic dispersion in WDM networks.

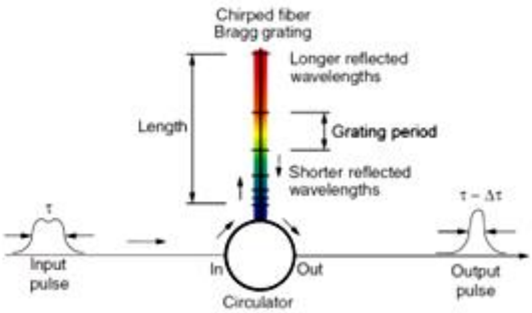

Fig. 1. Schematic of chirped FBG based dispersion compensation

The chromatic dispersion in the UDWDM-PON system can be compensated by means of the chirped FBG in the optical network. The basic principle of the dispersion compensation using a chirped FBG is illustrated in Fig.1. The broad optical pulse due to the dispersion is fed into the chirped FBG through the circulator at the output. The width of the input pulse decreases by Δτ and pulse is reconstructed in its original shape. The chirped FBGs have longer grating period towards the one end and relatively shorter grating period at the other beginning end. Due to the chirping the FBG, the small wavelength signals are reflected sooner and have small propagation delay along the FBG. On the other side, the larger wavelength signals are reflected later so the propagation delay is large through the FBG [20].In this way, different wavelengths are reflected through different grating portions and resulting different amount of group delay. For a linear chirped FBG the group delay and dispersion (i.e. the rate of change of delay with wavelength) can be calculated from the phase information of power reflectivity spectrum as [21]:

$$t_\rho = \frac{d\theta}{d\omega} = -\frac{\lambda^2}{2\pi c}\frac{d\theta}{d\lambda} \tag{2}$$

$$D_\rho = \frac{d\tau_\rho}{d\lambda} = -\frac{2\pi c}{\lambda^2}\frac{d^2\theta}{d\omega^2} \tag{3}$$

here, τ_ρ and D_ρ represent the group delay and the dispersion parameters respectively and θ is the phase of the power reflectivity spectrum.

The ideal dispersion FBG is used to overcome the effect of chromatic dispersion and simultaneously to increase the transmission distance. The FBG has the bandwidth of 1 THz and dispersion parameter of -2000ps/nm.km. The central frequency of the FBG is 193.1THz.

3. Circuit design and simulation

The circuit diagram of 16 channels UDWDM PON has been designed using commercially available OptiSystem software and shown in Fig.2. As illustrated in figure, at the transmitter side the source is a 16-portcontinuous wave laser array. The starting central frequency of the first port is 193.1THz. The network is UDWDM and the frequency spacing is of 25 GHz. In the simulation, the initial phase and line width both are considered as negligible. In the designing of this UDWDM-PON system 16 identical subsystems are used. To generate a bit sequence each subsystem encompasses a pseudorandom bit sequence generator (PRBS) and NRZ/DRZ pulse generator to encode the bit sequence.

In the circuit link a chirped fiber Bragg grating has been used to minimize the effect of linear chromatic dispersion and to increase the link length of the network at 1550 nm wavelength. The bandwidth of used FBG is 1 THz. In the circuit the post configuration is used to compensate the dispersion. In order to overcome the nonlinearities of signal the EDFA with the gain of 30 dB and noise margin of 4 dB has been used.

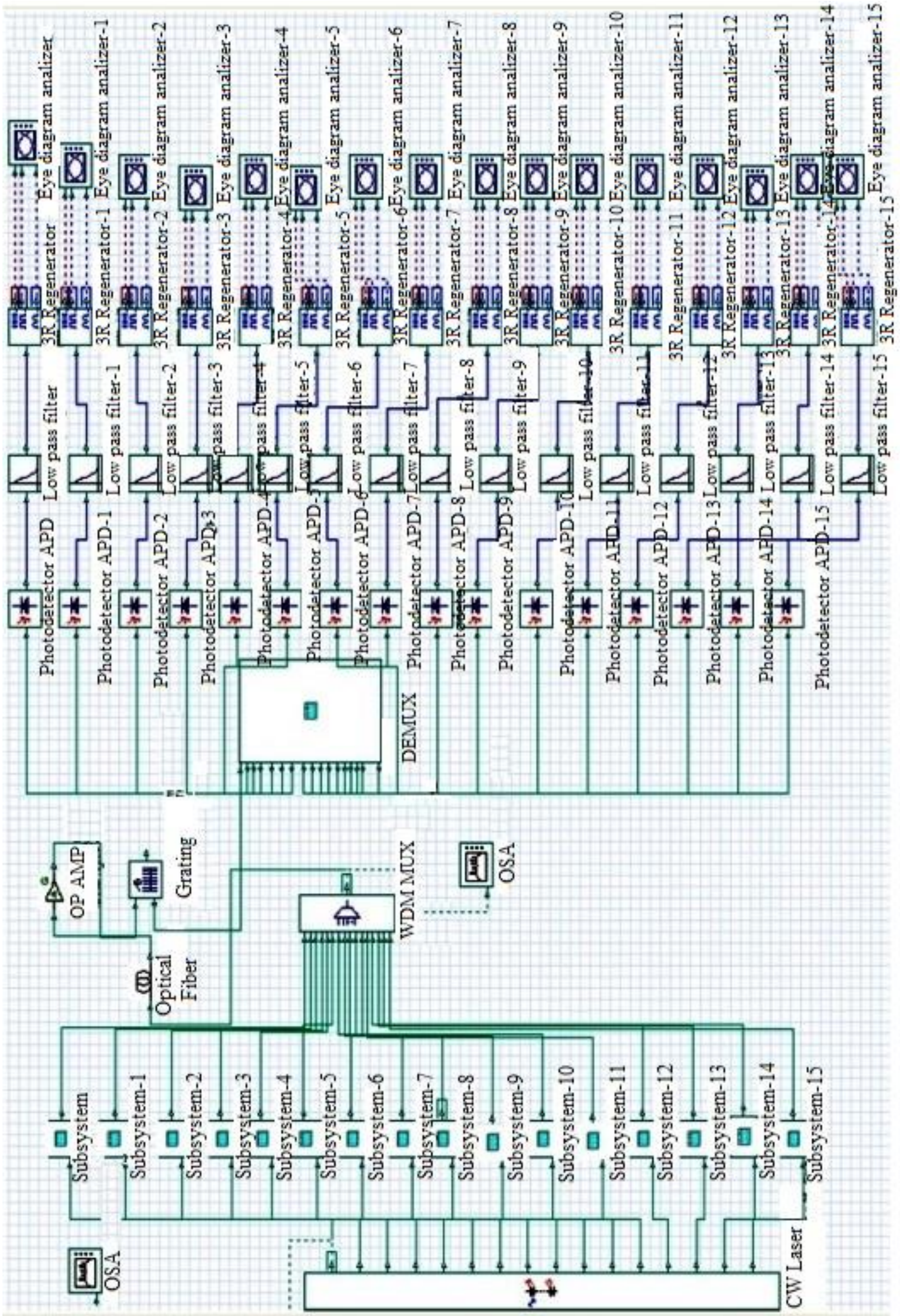

Fig. 2. Circuit diagram of the designed UDWDM PON.

4. Results and discussion

When the network is operated on the high data rate of 10 Gbps, the chromatic dispersion occurs in the system that limits the link length. Therefore, to reduce the dispersion we have used FBG as dispersion compensator in the network. According to the ITU-T for telecommunication application, the maximum tolerable value of bit-error-rate (BER) is 10^{-9}. There is a trade-off between the quality factor and BER.As the BER increases the value of quality factor decreases. Therefore, the proposed UDWDM-PON system has been optimized to achieve high quality factor with minimum BER.

Once the UDWDM-PON system has been designed the results of the designed network have been observed through eye diagram in terms of Q-factor. The simulation parameters that are used to design the network are shown in the table-1.

Table 1. Parameters used in the designing of UDWDM-PON system

Bit Rate	10 Gbps
Sequence Length	128
Samples/bit	32
WDM channel spacing	25 GHz
Central Frequency	193.1 THz
Capacity	10 Gbps×16 Channel

The variation of the quality factor on input signal power without using dispersion compensation technique has been illustrated in Fig.3. The maximum quality factor of the UDWDM-PON system comes out to be 8.36807 and 7.88401 with BER of 2.92840×10^{-17} and $1.58441\times10^{-15}$for NRZ and DRZ modulation techniques respectively at the data rate of 10 Gbps. As shown in Fig.4, the maximum value of the quality factor using the FBG as a dispersion compensator comes out to be 8.18965 and 8.82675 with BER of 1.03779×10^{-16} and 4.18060×10^{-18} for NRZ and DRZ modulation techniques.

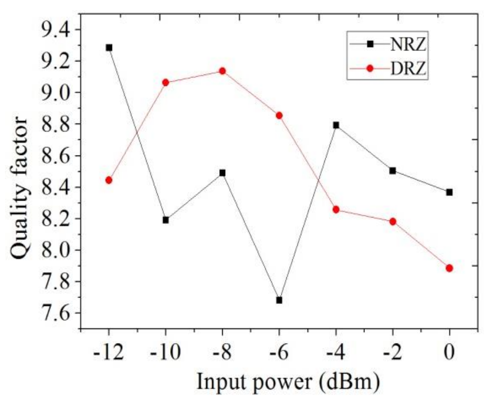

Fig. 3. The variation of the quality factor on input power without dispersion compensation technique

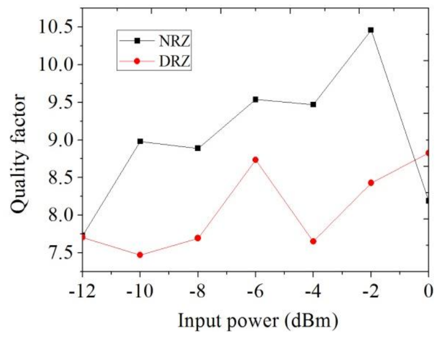

Fig. 4. The variation of the quality factor on input power using FBG as dispersion compensation technique

The effect of the input signal power on the maximum reachable distance of communication network without using FBG as a dispersion compensating device has been shown in Fig. 5. The maximum span lengths of the network are 68 Km and 75 Km for NRZ and DRZ modulation techniques respectively. Further the span length has been improved by using the FBG as the dispersion compensator and illustrated in Fig. 6. The maximum span length of the network has been achieved upto 150 Km and 160 Km for NRZ and DRZ modulation techniques respectively at the data rate of 10 Gbps.

Therefore, the span length of the UDWDM-PON system can be significantly improved using the FBG as a dispersion compensation device in the network.

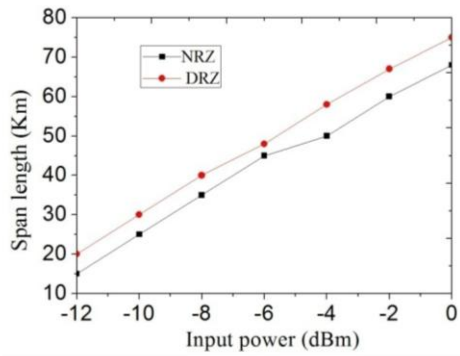

Fig. 5. The variation of the span length of the network on input power without dispersion compensation technique

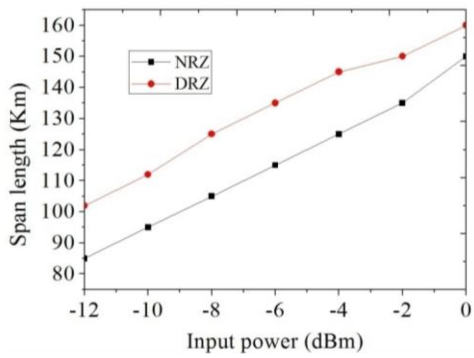

Fig. 6. The variation of the span length of the network on input power using FBG as dispersion compensation technique.

Finally, the comparison of the NRZ and DRZ modulation techniques has been shown in table-2. The quality factor, bit-error-rate and the span length of the UDWDM-PON with the loop control and FBG as dispersion compensation have been simulated for NRZ and DRZ techniques. The DRZ technique is superior to obtain larger maximum reach of the UDWDM-PON network.

Table 2. The quality factor, bit-error-rate and the span length of the UDWDM-PON with FBG as dispersion compensation and loop control (Total distance = 133×N; where N=3 (number of loops)

Input Power& Modulation Technique	Maximum quality Factor	Minimum BER	Maximum Distance (Km)
0 NRZ	8.15675	1.38540×10^{-16}	399
0 DRZ	8.06212	2.91202×10^{-16}	414

5. Conclusion

A 16 channel UDWDM-PON has been designed and analyzed to obtain low dispersion and long transmission length with high quality factor at 10 Gbps. The dispersion compensation using the fiber Bragg grating devices can provide a better solution in modern long haul communication systems. Chirped FBG based WDM DEMUX for 16 channels UDWDM-PON in terms of the quality factor and span length has been explored. Reported results illustrate that the fiber Bragg grating based DEMUX provides better performance in UDWDM-PON at high data rate of 10 Gbps. The use of the chirped fiber Bragg grating can boost the span length of the UDWDM-PON with better quality factor at 10 Gbps. Further the comparison between the NRZ and DRZ modulation technique based systems has been presented. It has been shown that the performance of DRZ based system is good as its decrement ratio in Q-factor is less and the span length is larger than that of NRZ based system.

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*Corresponding author: tsinghdph@gmail.com