Characteristics of Chirped Fiber Bragg Grating Dispersion Compensator Utilizing Two Apodization Profiles

Shaymaa R. Tahhan[1], Abdulla K. Abass[2], and Mudhafer H. Ali[3]
[1] Laser and Optoelectronics Engineering Department, College of Engineering, Al-Nahrain University, Baghdad, Iraq
[2] Laser Engineering Branch, Laser and Optoelectronics Department, University of Technology, Baghdad, Iraq.
[3]Network Engineering Department, College of Engineering, Al-Iraqiya University, Baghdad, Iraq.
Email: shaymaa.riyadh@gmail.com; 140042@uotechnology.edu.iq; muthafarh@yahoo.com

Abstract —In this work, the effects of two apodization functions on the performance of two dispersion compensators, namely, linear and quadratic chirps, based on chirped fiber Bragg grating (CFBG), are investigated and simulated. The hyperbolic tangent function (Tanh) represents the first profile, which is used directly from OptiSystem 13, while the second function is the sine cardinal (Sinc) profile, which is simulated by OptiGrating 4 software before this profile is incorporated in the OptiSystem. Tanh and Sinc profiles are simulated by linear and quadratic CFBGs for 100 GHz × 10 Gb/s wavelength division multiplexing system within two channels. Results indicate that the linear CFBG that is based on Sinc profile performance with an effective index of 1.46 represents an improved architecture for chromatic dispersion compensation. The proposed CFBG within both apodization profiles efficiently compensated the chromatic dispersion for fiber length > 90 km.

Index Terms—Chirped fiber bragg grating, dispersion compensation, duobinary modulation, sinc apodization, tanh apodization

I. Introduction

The fourth generation of optical communication systems uses an optical amplifier to increase repeater distance and Wavelength Division Multiplexing (WDM) to increase bit rate [1]–[4]. In addition the attenuation losses, chromatic dispersion, which results from the broadening of light pulses while they travel via the optical fiber, is considered the main drawback in any WDM communication system [5]. In this context, various approaches, such as dispersion compensation fiber [6], optical phase conjugation [7], Fiber Bragg Grating (FBG) [8], and high-order mode fibers (e.g., photonic crystal fiber) [9], have been proposed to compensate the chromatic dispersion along the transmitted channel. The FBG, as a dispersion compensator, has several advantages, such as low insertion losses, compact size, low cost, and wide compensation bandwidth with high resolution, over the dispersion compensation fiber [10], [11].

Several published works that are related to providing FBG as a dispersion compensation element in the WDM communication system have been reported. A short length of chirped fiber Bragg grating (CFBG) at approximately 10 mm can compensate dispersion from tens of kilometers of a single-mode fiber [12]. In 2004, Yitang Dai et al. designed and fabricated an equivalent nonlinear CFBG with linear dispersion in a channel for a precise tunable dispersion compensation. These authors achieved a 0.7 dB power penalty for 10 Gb/s with a span of 50 km SMF transmission experiment by inserting the tunable grating before the fiber link [13]. In 2009, Zhongwei Tan *et al*. introduced a zero BER for a long-haul optical fiber system of 3000 km transmission distance by utilizing the CFBG in a symmetrical compensation scheme. This system was proposed within a bit rate of 10 Gb/s and non-return to zero modulation format [14]. In 2010, Chaba and Kaler proved that FBG demonstrates the optimal performance among all dispersion compensation techniques, such as DCF, negative dispersion fiber, reverse dispersion fiber, and OPC for different bit rates [15].

FBG still encounters certain ripples in phase response and exhibits low tuning speed, although this reflector is considered an acceptable replacement to DCF and other approaches in terms of dispersion compensation issue. A superior performance in dispersion compensation was obtained from apodized FBG as a result of reducing side-lobe reflectivity and group delay ripple. Shermin et al. demonstrated an accurate selection of the apodized profiles with linearly CFBG when operated in the reflection in 2012 [16]. The integration of OptiGrating in the OptiSystem software enables the passive optical component, such as FBG, to spread in a wide range of applications, such as optical sensor [17], dispersion compensator applications [8], and monitoring system for a passive network [18], [19].

In this work, the effects of two apodization profiles, namely, Tanh and Sinc, on CFBG dispersion compensator are investigated under different chirp types and effective indices. The Tanh and Sinc profiles can be expressed as follows [16]:

$$f(z) = 1 + \mathrm{Tanh}\left[f\left(1 - 2\left(\frac{z}{L_G}\right)^{\alpha}\right)\right] \tag{1}$$

$$f(z) = Sinc^{X}\left(\left|\frac{2(z - L_G/2)}{L_G}\right|^{Y}\right) \tag{2}$$

where parameters α, X, and Y are used to control the apodization sharpness parameter, and L_G is the grating

Manuscript received Feb. 16, 2018; revised March 7, 2018.
Corresponding author email: 140042@uotechnology.edu.iq.
doi:10.12720/jcm.13.3.108-113

length. For complete theoretical details, the readers are directed to the following references [10], [16]. The challenge in this work is the comparison between two CFBGs based on Tanh and Sinc apodizations utilizing the combination between the two types of software, namely, OptiSystem 13 and OptiGrating 4.

II. Simulation Design

The simulation design includes three sections, namely, designing the Sinc CFBG by utilizing OptiGrating 4, designing Tanh CFBG by utilizing OptiSystem 13, and designing a 100 GHz × 10 Gb/s WDM system utilizing a pre-compensation CFBG within two channels. In order to deploy the Sinc CFBG as a dispersion compensator and compare with Tanh CFBG is exported as a spectrum file that is readable with OptiSystem. In this work, the CFBG parameters, such as grating length, effective index, and period of chirping, are selected based on the optimal results of the literature [16].

A. *Sinc CFBG Design*

The OptiSystem 13 does not contain the Sinc apodization profile in its library. Therefore, this profile was designed via the OptiGrating 4 software. The Sinc profile was imported from OptiGrating after a user-defined language code was programmed utilizing Equation (2). Fig. 1 displays the program flowchart for the Sinc code, while Fig. 2 exhibits the spectrum of designing the Sinc CFBG.

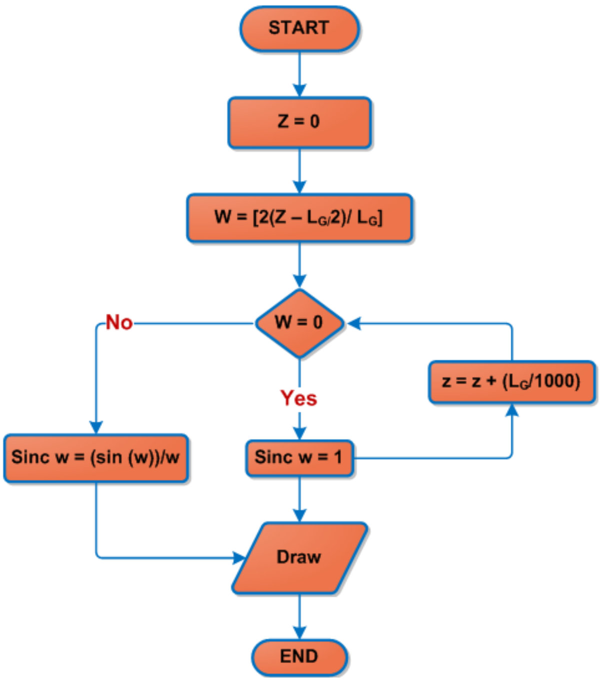

Fig. 1. Flowchart of the user-defined language code for Sinc formula in OptiGrating 4.

B. *Tanh CFBG Design*

The Tanh apodization profile is designed by utilizing OptiSystem 13, and the reflection spectrum is depicted in Fig. 3.

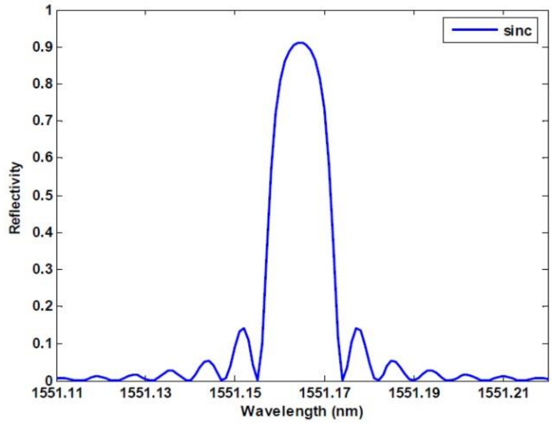

Fig. 2. Reflection spectrum of the Sinc apodization profile.

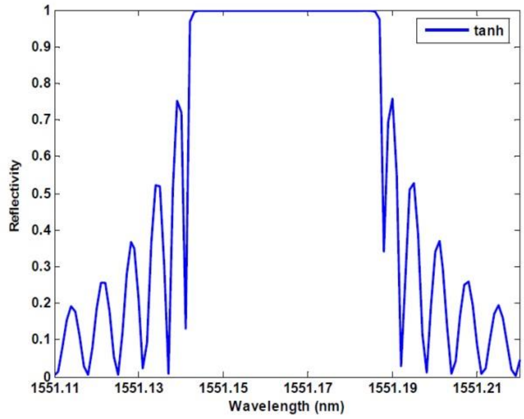

Fig. 3. Reflection spectrum of the Tanh apodization profile.

C. *Design of the WDM System Utilizing Pre-compensation CFBG*

Table I: Layout Parameters of the Simulation Design

Parameter	Value	Units
Bit rate	10	Gb/s
Time window	12.8e-9	s
Sample rate	160	GHz
Sequence length	128	Bits
Samples per bit	16	
Numbers of samples	2048	

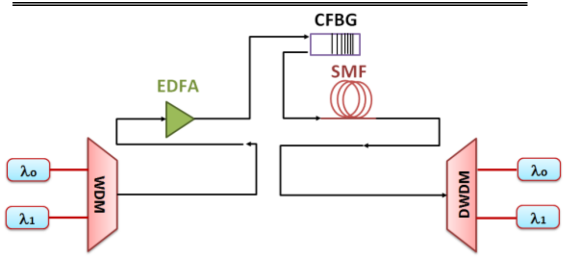

Fig. 4. Simulation setup of the WDM optical communication systems by utilizing pre-compensation CFBG.

The simulation setup of the WDM communication systems utilizing pre-compensation CFBG is illustrated in Fig. 4. This system includes three main parts, namely, transmitter, transmission line or channel, and receiver. These parts are clarified in the following subsections, and the layout parameters of the proposed work are listed in Table I.

1) Transmitter

The transmitter of the proposed WDM system is presented in Fig. 5. In this work, the duobinary modulation format, which is considered a three-level modulation technique, is adopted. The duobinary generator is fed by 40 Gb/s, 27−1 pseudo-random bit sequence generator, and binary NRZ modulation. Two LiNb MZMs with an extinction ratio of 30 dB are used. The first MZM modulates the amplitude of the input signal, whereas the second MZM modulates the phase over the entire input signal by a sine wave signal generator with a phase of −90°.

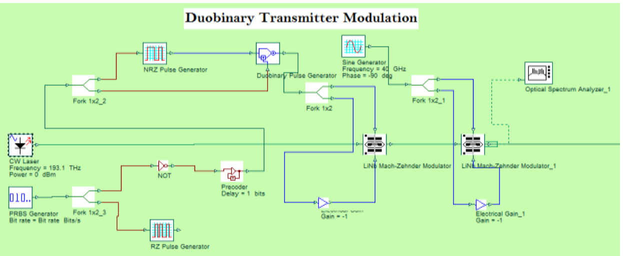

Fig. 5. Simulation setup of the transmitter part by utilizing duobinary modulation format.

2) Transmission line with the CFBG model

The proposed system is investigated by utilizing several SMFs that range from 10 km to 100 km with steps of 10 km. The dispersion of the used span is compensated using apodized pre-CFBG. Two apodization methods and two CFBGs were used to investigate and compare the performance of the pre-CFBG. The main simulation parameters for the SMF and CFBG are listed in Tables 2 and 3, respectively. In addition, two CFBG effective indices, that is, 1.46 and 1.95, are used in this work.

TABLE II: SMF PARAMETERS.

Parameter	Value
Attenuation (dB/Km)	0.2
Dispersion (ps/Km nm)	16
Dispersion slope (ps/Km nm)	0.08
Effective core area (μm^2)	80
Nonlinear effective index (n_2) (m^2/W)	2.6×10^{-20}

TABLE III: CFBG PARAMETERS

Parameter	Linear CFBG	Quadratic CFBG
Frequency (THz)	193.1, 193.2	193.1, 193.2
Effective Index	1.46, 1.95	1.46, 1.95
Length (mm)	100	100
Apodization function	Tanh Sinc	Tanh Sinc
Chirp Function	Linear, Quadratic (parameter = 0.0001)	Linear, Quadratic (parameter = 0.0001)

3) Receiving section

The received signal is filtered by a fifth-order Bessel optical filter, which was added after the demultiplexers, with an optimized bandwidth of 18 GHz, as displayed in Fig. 6. The received signal is detected by a PIN detector with a responsivity of 1 A/W. A low-pass Bessel filter with a cutoff frequency of 9 GHz is used to filter the detected signal. Finally, a 3R generator is combined with the BER analyzer to record the Q factor and BER.

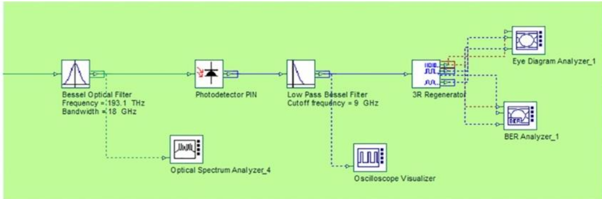

Fig. 6. Receiver section

III. RESULTS AND DISCUSSIONS

The effect of the different apodization profiles on the CFBG dispersion compensator is investigated under different chirp types and effective indices. The Tanh and Sinc profiles are simulated within the linear and quadratic CFBGs for 1.46 and 1.95 effective indices, correspondingly. In this work, two main parameters, namely, Q factor and BER are adopted to investigate and evaluate the performance of the proposed CFBG. The proposed CFBG is inserted as a pre-compensator for the 100 GHz × 10 Gb/s WDM system within two channels, namely, 193.1 and 193.2 THz, utilizing duobinary modulation format to evaluate and compare the performance of the proposed CFBG.

The Q factor and BER of the proposed CFBG is are investigated for different span lengths that range from 10 km to 100 km with steps of 10 km. Different EDFAs are used within a gain level that ranges from 2 dB to 20 dB with steps of 2 dB to compensate the attenuation losses, which were associated with the span lengths. Fig. 7 and Fig. 8 display the results of the Q factor and BER as a function of span length, respectively, for different effective indices.

According to the Q-factor results, the Sinc profile showed similar behavior for linear and quadratic CFBGs and for the same effective indices of 1.46 and 1.95, as depicted in Fig. 7 (a) and (b), respectively. As the fiber length increased from 10 km to 100 km within the effective index of 1.46 the Q-factor values are decreased from 25.6 to 4.8 and from 25.4 to 3.4 for linear and quadratic CFBG, respectively. An effective index of 1.95 reflects low Q factor values, which range from 16.2 to 2.4 for linear CFBG and from 14.8 to 2.5 for quadratic CFBG. These findings indicated that the Sinc profile within the effective index of 1.46 performs well in terms of Q factor.

Furthermore, the Tanh profile within the linear CFBG indicates a higher Q factor and better performance than the quadratic CFBG for the same effective indices, which ranged from 11.9 to 8 and from 3.1 to 2.1 for linear and quadratic CFBGs, respectively, within an effective index of 1.46. Moreover, an effective index of 1.46 denotes higher Q factor values than an effective index of 1.95. The Q-factor values for the linear CFBG are degraded from 11.9 to 8.6 and 8.3 to 2.7 for effective indices of 1.46 and 1.95, respectively. Finally, the proposed CFBG within the effective index of 1.46 at different conditions performs better than the CFBG within an effective index of 1.95.

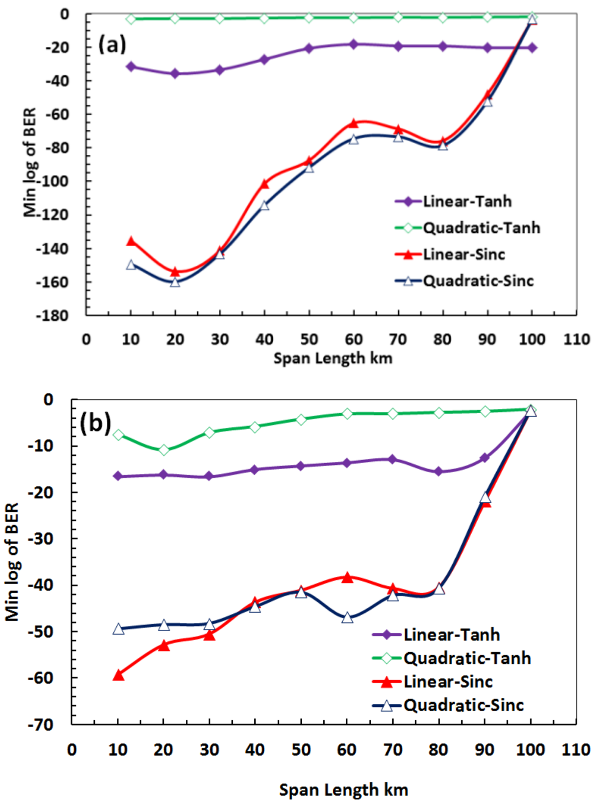

Fig. 7. BER versus span length with different CFBGs for effective indices of (a) 1.46, (b) 1.95.

An input signal power (Pin) is varied from −10 dBm to 20 dBm with a step of 5 dBm for the Sinc CFBG to examine the influence of Pin on the system performance. Fig. 8 depicts the Q factor as a function of the Pin for the Sinc CFBG under different conditions. The results of the Q factor versus the Pin can be divided into two regions.

At first, the Q factor exhibits a direct relationship with the Pin and then starts to degrade at a certain signal power >5 dBm and >10 dBm for an effective index of 1.95 and 1.46, respectively. This result can be attributed to the following: the increment in the Pin leads to an increase in the nonlinear effects, and the signal−to−noise ratio is degraded. In addition, the Q factor in the quadratic CFBG is degraded earlier than the linear chirp.

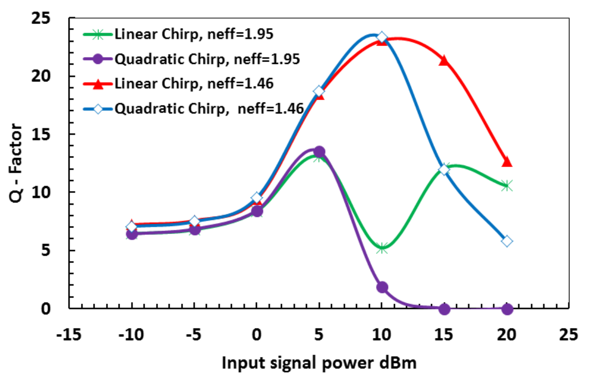

Fig. 8. Q factor versus Pin for Sinc apodization function at a span length of 80 km.

The pre-compensation scheme with the Sinc linear CFBG at an effective index of 1.46 clearly represents the optimum scheme among the other proposed types. Therefore, the Q factor and BER versus the Pin are investigated for the optimum scheme, and the eye diagram is illustrated at several signal powers, as demonstrated in Fig. 9.

The Q factor and BER exhibit an acceptable performance for Pin <15 dBm with the values of 23 and −120 for Q factor and BER, respectively, at a fiber length of 80 km and Pin of 10 dBm. In addition, acceptable dispersion compensation is achieved in terms of signal quality and eye shape, as depicted in the inset in figures, and the edge neat graph is symmetrical. Moreover, the increment in the input signal to 15 dBm increased the minimum log of BER to −101, degraded the Q factor to 21, and worsened the eye shape, but these values remain favorable and acceptable.

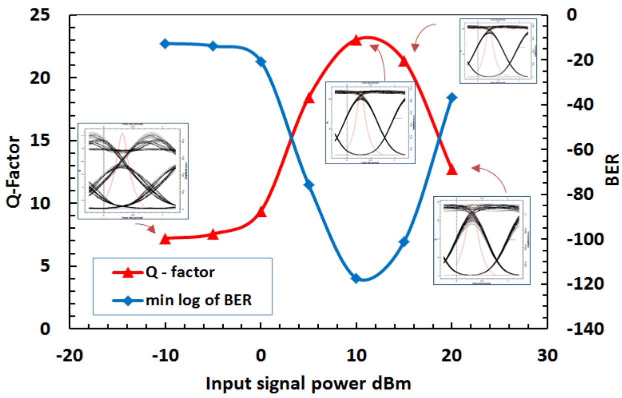

Fig. 9. Q factor and BER versus Pin for linear chirp Sinc apodized with an effective index of 1.46.

IV. Conclusions

In this work, we simulated and evaluated the performance of two apodization functions, namely, Tanh and Sinc profiles, based on CFBG for dispersion compensation by utilizing OptiSystem 13. We adopted two chirp types called linear and quadratic with two effective indices, that is, 1.46 and 1.95. The Sinc apodization function results showed overall superior performance in maximum Q factor and minimum BER compared with the Tanh function. In addition, the Sinc linear CFBG within the effective index of 1.46 performed better than other Sinc CFBGs for all span lengths used in this investigation. The proposed CFBG within both apodization profiles efficiently compensated the chromatic dispersion for fiber length > 90 km and performed well for fiber length < 80 km.

References

[1] G. Keiser, *Optical Communications Essentials*, USA: McGraw-Hill, 2003.

[2] M. H. Ali, F. Abdullah, M. Z. Jamaludin, M. H. Al-Mansoori, A. K. Abass, and T. F. Al-Mashhadani, "Effect of cascading amplification stages on the performance of

serial hybrid fiber amplifier," *Fiber Integr. Opt.*, vol. 34, no. 3, pp. 157–170, 2015.

[3] M. H. Ali, F. Abdullah, M. Z. Jamaludin, M. H. Al-Mansoori, T. F. Al-Mashhadani, and A. K. Abass, "Simulation and experimental validation of gain-control parallel hybrid fiber amplifier," *J. Opt. Soc. Korea*, vol. 18, no. 6, pp. 657–662, 2014.

[4] A. K. Abass, M. H. Al-Mansoori, M. Z. Jamaludin, F. Abdullah, and T. F. Al-Mashhadani, "Raman amplification effects on stimulated Brillouin scattering threshold in multiwavelength Brillouin-Raman fiber laser," in *Proc. 3rd International Conference on Photonics*, 2012, pp. 171–174.

[5] F. G. Smith, T. A. King, and D. Wilkins, *Optics and Photonics : An Introduction*, 2nd Editio. John Wiley & Sons Inc., 2007.

[6] H. H. Lu, "Performance comparison between DCF and RDF dispersion compensation in fiber optical CATV systems," *IEEE Trans. Broadcast.*, vol. 48, no. 4, pp. 370–373, 2002.

[7] J. Li, K. Xu, G. Zhou, J. Wu, and J. Lin, "Dispersion-compensation schemes for 160-Gb/s 1200-km transmission by optical phase conjugation," *J. Light. Technol.*, vol. 25, no. 8, pp. 1986–1995, 2007.

[8] S. R. Tahhan, M. H. Ali, and A. K. Abass, "Characteristics of dispersion compensation for 32 channels at 40 Gb / s under different techniques," *J. Opt. Commun.*, pp. 1–9, 2017.

[9] S. Kabir, G. K. M. Hasanuzzaman, and M. A. G. Khan, "Design of a dispersion flattened germanium doped silica modified hexagonal photonic crystal fiber with ultra low confinement losses," in *Proc. 1st International Conference on Electrical and Electronic Engineering*, November 2016, pp. 113–116.

[10] A. B. Dar and R. K. Jha, "Chromatic dispersion compensation techniques and characterization of fiber Bragg grating for dispersion compensation," *Optical & Quantum Electronics*, vol. 49, no. 3, 2017.

[11] S. R. Tahhan, R. Z. Chen, S. Huang, K. I. Hajim, and K. P. Chen, "Fabrication of fiber bragg grating coating with TiO2 nanostructured metal oxide for refractive index sensor," *J. Notechnology*, vol. 2017, pp. 1–9, 2017.

[12] G. Agrawal, *Fiber-Optic Communication Systems*, 3rd ed. New York: John Wiley & Sons, Inc., 2002.

[13] Y. Dai, X. Chen, L. Xia, Y. Zhang, and S. Xie, "Sampled Bragg grating with desired response in one channel by use of a reconstruction algorithm and equivalent chirp," *Opt. Lett.*, vol. 29, no. 12, pp. 1333–1335, 2004.

[14] Z. Tan, *et al*., "Transmission system over 3000 km with dispersion compensated by chirped fiber Bragg gratings," *Optik (Stuttg)*, vol. 120, no. 1, pp. 9–13, 2009.

[15] Y. Chaba and R. S. Kaler, "Comparison of various dispersion compensation techniques at high bit rates using CSRZ format," *Optik (Stuttg)*, vol. 121, no. 9, pp. 813–817, 2010.

[16] S. S. A. Khan and M. S. Islam, "Determination of the best apodization function and grating length of linearly chirped fiber Bragg grating for dispersion compensation," *J. Commun.*, vol. 7, no. 11, pp. 840–846, 2012.

[17] M. M. Elgaud, M. S. D. Zan, A. A. G. Abushagur, and A. A. A. Bakar, "Analysis of independent strain-temperature fiber bragg grating sensing technique using OptiSystem and OptiGrating," in *Proc. 6th International Conference on Photonics Analysis*, 2016, pp. 5–7.

[18] A. M. Abobaker, I. Eldbib, H. Daw, and P. R. Babu, "Testing a real time monitoring system for passive optical networks using an array of fiber Bragg gratings," *Int. J. New Comput. Archit. their Appl.*, vol. 4, no. 3, pp. 146–155, 2014.

[19] N. F. Naim, M. S. Ab-rahman, H. A. Bakarman, and A. A. A. Bakar, "Real-Time monitoring in passive optical networks using a superluminescent LED with uniform and phase-shifted fiber Bragg gratings," *J. Opt. Commun. Netw.*, vol. 5, no. 12, pp. 1425–1430, 2013.

Shaymaa R. Tahhan was born in Babylon, Iraq, in 1982. She received the B.Sc. degree and her M.Sc. degree in Laser and optoelectronics engineering from Al-Nahrain University, Baghdad, Iraq, in 2003 and 2008, respectively. She received the Ph.D. in electronics and communication engineering/ laser applications from University of Baghdad (theoretical) and Pittsburgh University (research), Baghdad, Iraq and Pennsylvania, USA respectively, in 2014. Her employment experience includes working in optical fiber, spectroscopy and laser systems laboratories. Her special fields of interest include optical fiber systems specially fabrication of fiber Bragg grating FBG and employing it in sensors and as dispersion compensation in communication systems. Since 2016, she has been a staff member in the Laser and Optoelectronics Engineering Department, Al-Nahrain University, Iraq.

Abdulla K. Abass was born in Baghdad, Iraq, in 1976. He received the B.Sc. degree in electrical and electronics engineering and his M.Sc. degree in laser and optoelectronics engineering from Al-Rasheed College of Engineering and Science, University of Technology, Iraq, in 1999 and 2004, respectively. He received the Ph.D. in optical communications from Universiti Tenaga Nasional (UNITEN), Malaysia, in 2015. His employment experience includes working in optoelectronics and laser applications laboratories. His special fields of interest include laser systems and laser applications. Since 2004, he has been a staff member in the Laser and Optoelectronics Engineering Department, University of Technology, Iraq.

Mudhafer H. Ali received his B.Sc. in electrical and electronics engineering and his M.Sc. in laser and optoelectronics engineering from Al-Rasheed College of Engineering and Science, University of Technology, Iraq, in 1996 and 2004, respectively. His employment experience includes the Research and Development Center in Ministry of Science and Technology. His special fields of interest include fiber amplifiers, laser systems and applications. By 2004, he was a

chief of engineers at the Ministry of Science and Technology/Renewable Energy Center. 1n 2015, he received his Ph.D. in communications engineering from Universiti Tenaga Nasional. Since 2016, he has been a staff member in the Network Engineering Department, College of Engineering, Al-Iraqia University, Iraq.