JPPIPA 8(2) (2022)

Jurnal Penelitian Pendidikan IPA
Journal of Research in Science Education

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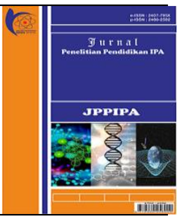

High-Performance Compensation Dispersion with Apodization Chirped Fiber Bragg Grating for Fiber Communication System

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DOI: 10.29303/jppipa.v8i2.1521

Article Info
Received: March 10, 2022
Revised: April 23, 2022
Accepted: April 26, 2022
Published: April 30, 2022

Abstract: The effect of dispersion will interfere with the signal transmission. Several ways can be done in compensating the dispersion such as by utilizing dispersion compensator fiber (DCF) or chirp fiber Bragg grating (CFBG). The dispersion compensation schemes with DCF are expensive and it also causes nonlinear optical effects, meanwhile, the CFBG can reduce costs and promise better results. In this study, an Apodization Chirped Fiber Bragg Grating (ACFBG) has been developed as a dispersion compensator with Optisystem with non-return to zero (NRZ) 20 Gbps. It is found that the Gaussian Cubic-CFBG apodization with a size of 90 mm had the highest Q-factor evaluation of 20,776 dB for a 250 km dispersion compensation scheme. This result is much larger than the previous CFBG dispersion compensation scheme. This study also confirmed that the Gaussian Apodization was the best profile compared to Tanh Apodization, from the evaluation of the Q-factor, Tanh cubic-CFBG only obtained a Q-factor of 9.6 dB. Certainly, the high performance of ACFBG as a dispersion compensator is very useful to support optical communication systems.

Keywords: ACFBG; Compesation Dispersion; Optical Transmission; Chirped; Apodization.

Citation: Irawan, D. ., Azhar, A., & Ramadhan, K. (2022). High-Performance Compensation Dispersion with Apodization Chirped Fiber Bragg Grating for Fiber Communication System. *Jurnal Penelitian Pendidikan IPA*, *8*(2), 992–999. https://doi.org/10.29303/jppipa.v8i2.1521

Introduction

In optical communication systems, the important thing is how to maintain the transmitted signal as the transmission distance increases. Power losses and dispersion events are unavoidable and are major factors limiting maximum data rates. In optical communication networks, optical amplifiers are used for long periods, and it is necessary to use repeaters and wavelength division multiplexing (WDM) to increase the bit rate (Karpagarajesh et al., 2021; Sayed et al., 2020; Sayed et al., 2021), Apart from widening and reducing power, chromatic dispersion can also cause pulse widening when traveling through optical fiber, this is considered a major drawback in WDM communication systems (Kahlon & Kaur, 2014; Aladadi et al., 2016; Azhar et al., 2022; Khusnul et al., 2022; Syahfira et al., 2021). In this context, several approaches such as dispersion compensated fiber, optical phase, fiber Bragg gratings (FBG) (Mohammed et al., 2014), and high order mode fiber (such as photonic crystal fiber) are proposed to compensate for chromatic dispersion along the transmission line. FBG as a dispersion compensation component has several advantages such as low insertion loss, small size, low cost, wide bandwidth compensation with high resolution, dispersion compensated in passive and compatible fiber (Irawan et al., 2010; Irawan et al., 2012; Naim et al., 2020; Irawan et al., 2015).

Overcoming dispersion is an important focus in optical communication for long-distance transmission, some authors recommend ways to overcome this, such as using EDFA (Erbium-doped fiber amplifier) to compensate for signal loss (Choi et al., 2003), using Dispersion compensation fiber (DCF) with relying on negative dispersion that can compensate for signal

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dispersion (Meena and Meena, 2020), and using fiber Bragg grating (FBG) which can compensate for dispersion well, besides that FBG can also reduce the impact of optical nonlinearity, low cost and can work in WDM schemes. DCF technology has three compensation schemes used, namely, pre, under, and mixed compensation (Hussein et al., 2019; Meena & Gupta, 2019; Ranathive et al., 2019). DCF is stable and not easily affected by temperature, but has internal losses and high costs. Nevertheless, FBGs are chosen to compensate for dispersion, Dispersion compensation with this type of FBGs can be used for pulse compression in two schemes. Reflective and transmission base system. The basic reflective system is described to exhibit complete compression, but the system requires a coupler to extract the reflected and re-pressurized pulses. Therefore, they result in a loss in incremental insertion (Mustafa et al., 2019).

Several articles have found links to utilizing an FBG as a dispersion compensation element in WDM communication systems that have been widely reported (Irawan et al., 2012). The grating length of CFBG of about 10 mm can compensate for the tens of kilometers dispersion of a single single-mode mode fiber (SMF). The design and fabrication of non-linear CFBG equivalent to channel linear dispersion for precise tunable compensation of dispersion is constantly evolving, and even reaching absolute strengths of 0.7 dB to 10 Gb/s over a 50 km SMF by providing a tunable grid to the fiber link (Irawan et al., 2020). The Bit Error Rate (BER) was also introduced to zero for long-distance fiber optic systems with a transmission distance of 3,000 km using CFBG with an asymmetric compensation scheme. The system is proposed with a bit rate of 10 Gb/s and a non-return to zero modulation form. FBG has provided optimal performance among all dispersion compensation techniques, such as DCF, reverse dispersion fiber, OPC, and negative dispersion fiber, for different bit rates. In another work, Muhammad used raised cosine apodization in DFB-F (Distributed feedback fiber with an FBG size of 30 mm and obtained FWHM (Full Width half maximum) of 0.044 nm (Dar & Jha, 2017; Tahhan et al., 2018).

Some work has been reported in compensating dispersion such as doing WDM, using pre/post and symmetrical DCF for a fiber length of 300 km, and using a bit rate of 10 Gbps, the performance is carried out by taking into account the Q factor, BER (bit error rate) and eye diagram (Kaur et al., 2015), WDM systems can increase the nonlinear effect of fiber and are also expensive. Bhadway and Soni demonstrated an optical communication model to compensate for dispersion for the difference in fiber length with a bit rate of 20 Gbps (Bhardwaj & Soni, 2015). Deepika then compared the dispersion compensation scheme with FBG with a grating length of 90 mm for 210 km fiber. It was found that the Q-factor could be increased by 50% compared to the results obtained by Sayed et al (Sayed et al., 2017). Polymer materials can also be an alternative in reducing the cost of dispersion compensators, polymers have a higher refractive index than silica and also have the best performance (Min et al., 2018).

In general, CFBG is the best way to compress FBG pulses, in this paper a CFBG dispersion compensation scheme by associating multiple apodizations (ACFBG) and low cost is offered for optical fiber with length up to 250 km, performance based on Q-factor and BER ACFBG being comparison in previous papers using the Optisystem simulator.

Method

Simulations were carried out using optigrating software and optisystem software, ACFBG was designed using an effective refractive index of 1.47 (Saktioto et al., 2021), (Ramadhan & Saktioto, 2021). The resulting design in the Optigrating software is exported and entered into a series in the Optisystem software as shown in the figure 1:

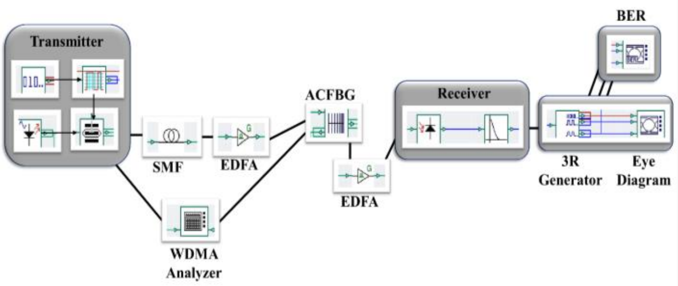


Figure 1. The optical circuit on Opti system

Figure 1 presents a compensation scheme using ACFBG in WDM optical communication. The transmission signal uses power of 17 dBm the same parameter is also used in the previous research scheme reported, and uses a pseudo-random bit sequence (PRBS) at a speed of 10 Gb/s, then the signal will be entered with a binary code (0 1) and connected to a Mach-Zehnder modulator with an attenuation ratio of 30 dB, in this case, the Mach-Zehnder modulator is used to divide the phase of the wave, the first is connected to dual WDM ports, the other arm is connected to a 250 km optical fiber. The parameters used in the simulation scheme can be shown in the Table 1.

Table 1. The parameters of the SMF

Parameters	Value
Dispersion on fiber (ps/nm/km)	17.25
Dispersion slope (ps/nm2/km)	0.085
Power laser CW (dBm)	17
Attenuation on fiber (dB/km)	0.2
Optical fiber length (km)	250
Gain (dB) of EDFA amplifier with 4 dB NF	40 and 10

In Table 1 above, the SMF is set with a variance parameter of 17.25 ps / nm / km. When the signal passes through a 250 km optical fiber, the signal passes through the EDFA with different intensities of 40 dB and 10 dB at the same noise rate of 4 dB. This reinforcement is intended to overcome signal loss during the 250km transmission process (Irawan et al., 2019). The signal then passed through the CFBG, compensating for the dispersion generated within the signal, and connecting an EDFA with a gain of 10 dB between the output of the CFBG and the input of a PIN photodetector capable of converting the optical signal. For electrical signals. The output signal was then filtered with a Bessel filter and optical reproduction, the simulation results were displayed in the form of an eye pattern using an eye pattern analyzer, and the BER or Q factor of the proposed model was calculated. You can check the signal quality pattern of the entire transmission with the BER analyzer.

Table 2. Optimized paramters of the ACFBG

Parameters	Value
Refractive index	1.47
Frequency (THz)	193.1
Grating length (mm)	90
Apodization parameters	0.5
Chirp parameters	0.0001
Delta lambda (nm)	1

Table 2 shows the parameters set in ACFBG, with an effective refractive index of 1.47 and a grating length of 90 mm, this grating length was chosen the same as reported by previous studies for maximum results, further the effect of apodization and FBG chirp on the Q-Factor will be analyzed.

Result and Discussion

First in this work to design an ACFBG with a grating length of 90 mm, several ACFBG parameters are defined in the Optigrating software as shown in table 1. After designing the ACFBG, the design data is exported and entered into the optical circuit that has been compiled in the Optisystem in the picture above. The optical circuit was carried out using a 17 dBm laser this value was the same as the work carried out by the last reported study (Meena & Meena, 2020). Therefore, BER and Q-factors have the relationship shown in Equation (1)

$$BER = \frac{1}{\sqrt{2\pi}} e^{-\frac{Q^2}{2}} \qquad \ldots\ldots\ldots\ldots (1)$$

Chromatic dispersion and non-linear effects can reduce the signal and cause a little error in the network system, the higher the Q-factor value, the lower the probability of errors. Bit Error Rate (BER) is the value of events in digital transmission systems, where this measure is a measure of the quality of the signal in a digital communication system. BER is a crucial parameter applied to monitor systems that transmit digital data from one point to another. BER is the ratio between the error or bit damage (error) with the whole sent bit with Equation 14.

$$BER = \frac{N_E}{N_T} \qquad \ldots\ldots\ldots\ldots (2)$$

And here are some types of profile apodization and its functions (Saktioto et al., 2021):

Gaussian function

$$A(x) = \exp\left(-\ln 2\left(\frac{2\left(x-\frac{L}{2}\right)}{0.5L}\right)^2\right) \qquad \ldots\ldots (3)$$

and The types of CFBG can be seen in the equation (4)-(7).

Linear:

$$\Lambda(z) = \Lambda_o - \frac{z-\frac{L}{2}}{L}\Delta \qquad \ldots\ldots\ldots\ldots (4)$$

Quadratic:

$$\Lambda(z) = \Lambda_o - \left[\left(\frac{z}{L}\right)^2 - \frac{1}{4}\right]\Delta \qquad \ldots\ldots\ldots\ldots (5)$$

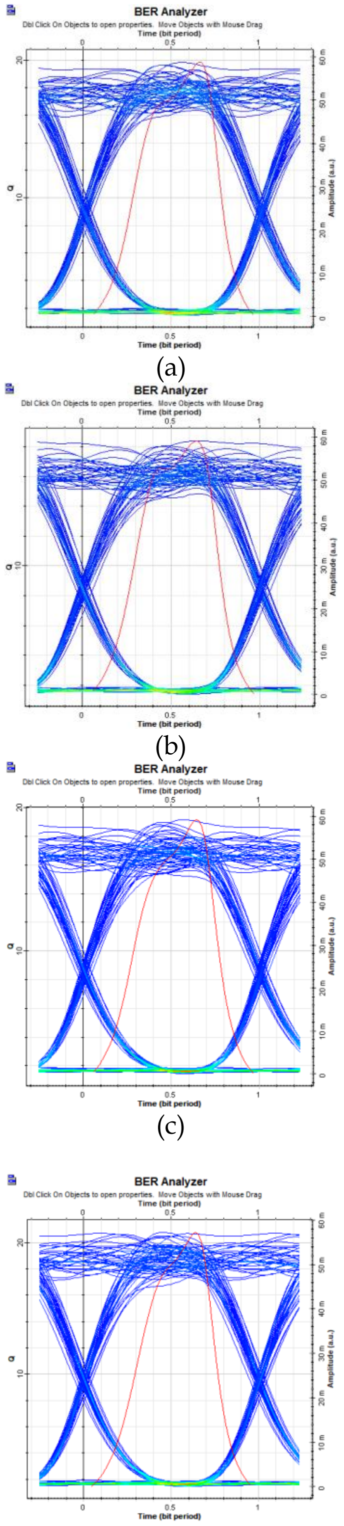
Square root:

$$\Lambda(z) = \Lambda_o - \left[\left(\frac{z}{L}\right)^{1/2} - \frac{1}{\sqrt{2}}\right]\Delta \qquad \ldots\ldots\ldots\ldots (6)$$

Cubic root:

$$\Lambda(z) = \Lambda_o - \left[\left(\frac{z}{L}\right)^{3/2} - \frac{1}{\sqrt[3]{2}}\right]\Delta \qquad \ldots\ldots\ldots\ldots (7)$$

The results of the eye diagram and BER can be seen as shown in the Figure 3 :



(a)

(b)

(c)

(d)

Figure 3. (a) Gaussian Linear-CFBG, (b) Gaussian Quadratic-CFBG, (c) Gaussian Square-CFBG, (d) Gaussian Cubic-CFBG

Figure 3 shows the evaluation of the Q-factor value of each ACFBG for dispersion compensation, the apodization is chosen in this scheme is Gaussian apodization, variations of CFBG are associated in this scheme to evaluate the quality factor (Q-factor) of the transmission signal with a fiber range of 250 km. The optical circuit for dispersion compensation can be seen in Figure 2. SMF length of 250 km obtained a Q-factor evaluation for cubic-CFBG of 20.7671, this result has a better value than previous studies for the same scheme [8][17]. Deepika meena, obtained a Q factor for SMF length of 210 km of 18.46 dB. The proposed scheme has a better Q factor and it can transmit the signals further up to 250 km. The scheme was strongly related to the variation of CFBG, it has been obtained that Gaussian linear-CFBG has a Q-factor of 19.832 dB for the same SMF length. The Gaussian quadratic-CFBG and Gaussian square-FBG yielded Q-factor of 18.3708 dB and 19.1315 respectively. These results indicate that Gaussian cubic-CFBG has the best Q-factor in the 250 km dispersion compensation scheme. Then Gaussian Quadratic-CFBG got the lowest results among other CFBGs. However, this result is the best result compared to previous studies (Basil & Moutaz, 2021). The eye diagram analysis can be seen in the table 3.

Table 3. Eye diagram analysis for Gaussian-CFBG

CFBG	Max. Q factor (dB)	Min. BER	Eye- Height
Cubic-CFBG	20.7	2.64×10^{-96}	0.043
Linear-CFBG	19.8	5.7×10^{-88}	0.043
Quadratic-CFBG	18.4	7.99×10^{-76}	0.0428
Square-CFBG	19,1513	3.18×10^{-82}	0.0427

Table 3 shows the analysis for Gaussian apodization of each variation of CFBG. The Q factor which is the transmission signal quality factor can be seen in the table above, and it is proven that CFBG can compensate for the dispersion that occurs in long distance optical fiber transmission. CFBG can reduce costs when compared to DCF compensation schemes. DCF is expensive and also has disadvantages due to the nonlinear effect that occurs in optical fiber. Furthermore, Tanh apodization was evaluated in this scheme for each type of CFBG. Tanh profile equation (8).

$$A(x) = \tanh\left(4\frac{x}{L}\right)\tanh\left(\frac{1-x}{L}\right) \quad \dots\dots\dots\dots\dots\dots (8)$$

Where $0 \le x \le L$.

Tanh apodization shows less results than the Gaussian apodization profile, the results of the Q factor evaluation can be seen as shown in the Figure 4.

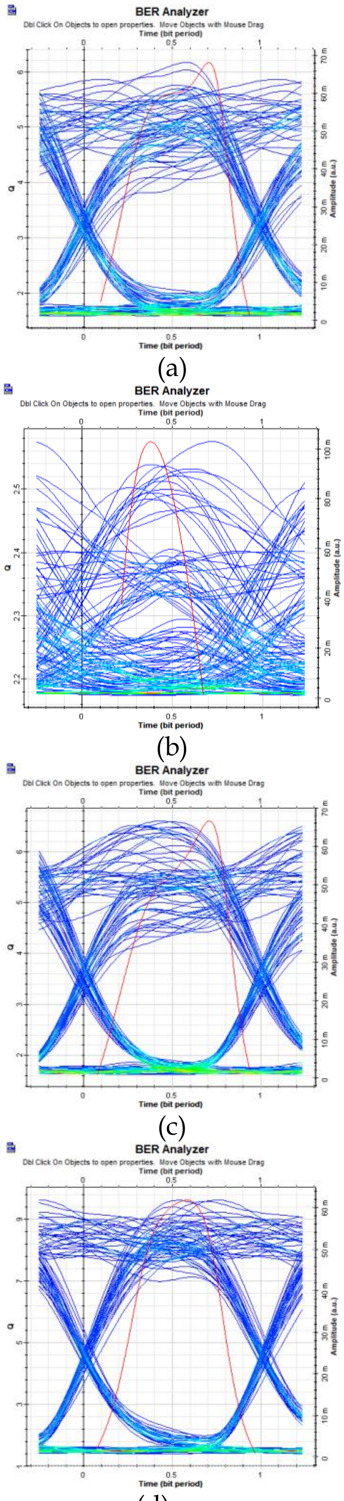


Figure 4. (a) Tanh linear-CFBG, (b) Tanh quadratic-CFBG, (c) Tanh square-CFBG, (d) Tanh cubic-CFBG

Figure 4 shows the BER analyzer of Tanh-CFBG. The results obtained are not as well as Gaussian apodization. However, the Tanh Cubic-CFBG type showed good results compared to other types of Chirping. It is found that the signal quality factor of the Tanh cubic-CFBG is 9.62 dB. And it's 50% better than Tanh square-CFBG with a Q-factor of 6.6 dB. Furthermore, the linear-CFBG Tanh obtained a Q-factor of 6.168 dB, the lastly the quadratic-CFBG Tanh obtained the worst Q-factor value compared to other types of CFBG. The dispersion compensation scheme in Tanh apodization is also treated the same as Gaussian apodization in Figure 3. A significant difference was obtained from the evaluation of signal quality factors between Gaussian and Tanh apodization. For ta cubic-CFBG obtained a Q-factor of 20.7 dB, this result is much larger than the Tanh cubic-CFBG of 9.62 dB. The difference that occurs is more than 100% from the side of the Q factor. Other variations of CFBG also obtained the same thing. Certainly, a Gaussian cubic-CFBG scheme is recommended in compensating the dispersion for a 250 km long SMF. and this result is the best result in this work and also much better than previous studies (Meena and Meena, 2020), (Sayed et al., 2017). The eye diagram analysis for Tanh apodization with chirp variations can be seen in the Table 4:

Table 4. Eye diagram analysis for Tanh CFBG

CFBG	Max D factor (dB)	Min BER	Eye Height
Square-CFBG	6.6	1.5 x 10^{-11}	0.0255
Linear-CFBG	6.168	2.97 x 10^{-10}	0.0244
Quadratic-CFBG	2.57	0.0046	-0.01
Cubic-CFBG	9.62	2.8 x 10^{-22}	0.033

Table 4 shows the eye diagram analysis for each CFBG, it was found that the Tanh apodization received a less favorable Q factor evaluation than the Gaussian apodization. The dispersion compensation scheme is proposed and compared with the compensation scheme carried out in the previous study. The following shows the results of differences in BER and Q factor values from previous studies. Which can be seen in table 5.

Table 5. Comparison of the results of Q factor and BER with related studies

SMF-length(km)	CFBG-length (mm)/ DCF length (km)	Q factor (dB)	BER	Reference
210	90 mm (Linear)	18.46	1.59 x 10^{-57}	(D. Meena & Meena, 2020)
200	80 mm (Linear)	7.94	1.96 x 10^{-14}	(Sayed et al., 2020)
210	90 mm	14.91	3.41 x 10^{-51}	(Sayed et al., 2017)
250	90 mm (cubic)	20.7	2.6 x 10^{-96}	Our scheme

In table 5 above we summarize the results of the comparison from previous research, the compensation dispersion scheme for SMF along 250 km, we obtained a better Q factor evaluation result of 20.7726 dB, compared to the work done by Depiika and sayed. With the same CW laser power, Depiika obtains a Q factor with a CFBG of 90 mm with a linear type of 18.46 bigger 2 dB compared to the scheme and the results we got and the SMF installed only 210 km long. 40 km longer than the one we installed on the optical circuit. To be clearer than previous studies, see the table above with a comparison of the length of CFBG or DCF and the resulting evaluation values of Q factor and BER.

Conclusion

Long-distance transmission has dispersion constraints due to distortion of the signal sent over the fiber. ACFBG has been designed to overcome dispersion, in this paper Gaussian cubic-CFBG has been designed and its performance evaluated using Q-factor. It ~~is~~ was obtained that Gaussian cubic-CFBG for transmission as far as 250 km has a Q-factor value of 20.7726 dB and BER of 2.6 x 10- 96, the effect of soil apodization is also evaluated in this paper and obtained Q-factor for Tanh cubic-CFBG of 9.62 dB and BER of 2.8 x 10-22. This ACFBG scheme is greater than the results obtained by previous researchers and has a length of 90 mm. Increasing the Q-factor will enhance the performance of ACFBG in terms of good dispersion compensator and cost less. However, a higher Q-factor will reduce the BER which occurs during signal transmission through an optical fiber.

Acknowledgements

We would like to thank LPPM Universitas Riau for their great support in this research. We also would like to thank physics education laboratory and plasma and photonics physics laboratory.

References

Aladadi, Y. T., Abas, A. F., & Alresheedi, M. T. (2016). Optimum apodization profile for chirped fiber bragg gratings based chromatic dispersion compensator. *Journal of the European Optical Society*, *12*(1). https://doi.org/10.1186/s41476-016-0006-8

Azhar, A., Fuadi, H., Doyan, A., Susilawati, S., Ayub, S., Hudha, L. S. (2022). Innovation of simple binoculars as a teaching aid for optical practicum at school. *Journal of Physics Conference Series, 2165.* https://doi.org/10.1088/17426596/2165/1/012031

Basil, N., & Moutaz, M. (2021). Design and Implementation of Chirp Fiber Bragg Grating for Long Haul Transmission System using Optisystem. *Informatica: Journal of Applied Machines Electrical Electronics Computer Science and Communication Systems*, *2*(1), 1–7.

Bhardwaj, A., & Soni, G. (2015). *Performance Analysis of Optical Communication System Using Fiber Bragg Grating*. *2*, 24–28.

Choi, B. H., Park, H. H., & Chu, M. J. (2003). New pump wavelength of 1540-nm band for long-wavelength-band erbium-doped fiber amplifier (L-band EDFA). *IEEE Journal of Quantum Electronics*, *39*(10), 1272–1280. https://doi.org/10.1109/JQE.2003.817582

Dar, A. B., & Jha, R. K. (2017). Chromatic dispersion compensation techniques and characterization of fiber Bragg grating for dispersion compensation. *Optical and Quantum Electronics*, *49*(3). https://doi.org/10.1007/s11082-017-0944-4

Hussein, T. F., Rizk, M. R. M., & Aly, M. H. (2019). A hybrid DCF/FBG scheme for dispersion compensation over a 300 km SMF. *Optical and Quantum Electronics*, *51*(4). https://doi.org/10.1007/s11082-019-1823-y

Irawan, D., Saktioto, ., & Ali, J. (2010). Linear and triangle order of NX3 optical directional couplers: variation coupling coefficient. *Photonic Fiber and Crystal Devices: Advances in Materials and Innovations in Device Applications IV*, *7781*, 77810J. https://doi.org/10.1117/12.862573

Irawan, D., Saktioto, Ali, J., Fadhali, M., & Erwin. (2012). Estimation of coupling parameters for auto-motorized fabrication of fused fiber coupler. *Microwave and Optical Technology Letters*, *54*(8), 1932–1935. https://doi.org/10.1002/mop.26937

Irawan, D., Saktioto, T., Iwantono, Minarni, Juandi, & Ali, J. (2015). An optimum design of fused silica directional fiber coupler. *Optik*, *126*(6), 640–644. https://doi.org/10.1016/j.ijleo.2015.01.031

Irawan, D., Saktioto, Ali, J., & Defrianto. (2011). Breakdown voltage effect on coupling ratio fusion fiber coupling. *Physics Procedia*, *19*. https://doi.org/10.1016/j.phpro.2011.06.195

Irawan, D, Fakhrudin, Z., Mustakim, Vebrianto, R., & Saktioto. (2020). Nanostructure Fusion Region of Single Mode Fiber Coupler. *Journal of Physics: Conference Series*, *1655*. https://doi.org/10.1088/1742-6596/1655/1/012001

Irawan, D, & Saktioto. (2019). Quantum Interpretation of Light Normalization at the Coupling Region Single Mode Fiber Coupling. *Journal of Physics: Conference Series*, *1351*, 12001. https://doi.org/10.1088/1742-

6596/1351/1/012001

Irawan, D, Saktioto, Ali, J., Erwin, & Defrianto. (2012). *Modeling of coupling parameters of directional fiber coupler based on degree of fusion*. https://doi.org/10.1109/escinano.2012.6149694

Kahlon, N. K., & Kaur, G. G. (2014). Various Dispersion Compensation Techniques for Optical System: A Survey. *Open Journal of Communications and Software*, *2014*(1), 64–73. https://doi.org/10.15764/cs.2014.01006

Karpagarajesh, G., Blessie, A., & Krishnan, S. (2021). Performance Assessment of Dispersion Compensation Using Fiber Bragg Grating and Dispersion Compensation Fiber Techniques. *Informacije MIDEM*, *51*(4), 215–223. https://doi.org/10.33180/InfMIDEM2021.402

Kaur, M., Sarangal, H., & Bagga, P. (2015). Dispersion Compensation with Dispersion Compensating Fibers (DCF). *IJARCCE*, 354–356. https://doi.org/10.17148/ijarcce.2015.4280

Khusnul, F., Nasir, M., Azhar, A. (2022). Optics visualization web-based as a physics learning media in senior high school, 6(1), 188-199. *Journal of Education Science.* Retrieved from *https://jes.ejournal.unri.ac.id/index.php/JES/article/view/8260/6788*

Meena, D., & Meena, M. L. (2020). Design and analysis of novel dispersion compensating model with chirp fiber bragg grating for long-haul transmission system. *Lecture Notes in Electrical Engineering*, *546*, 29–36. https://doi.org/10.1007/978-981-13-6159-3_4

Meena, M. L., & Kumar Gupta, R. (2019). Design and comparative performance evaluation of chirped FBG dispersion compensation with DCF technique for DWDM optical transmission systems. *Optik*, *188*, 212–224. https://doi.org/10.1016/j.ijleo.2019.05.056

Min, R., Korganbayev, S., Molardi, C., Broadway, C., Hu, X., Caucheteur, C., Bang, O., Antunes, P., Tosi, D., Marques, C., & Ortega, B. (2018). Largely tunable dispersion chirped polymer FBG. *Optics Letters*, *43*(20), 5106. https://doi.org/10.1364/ol.43.005106

Mohammed, N. A., Solaiman, M., & Aly, M. H. (2014). Design and performance evaluation of a dispersion compensation unit using several chirping functions in a tanh apodized FBG and comparison with dispersion compensation fiber. *Applied Optics*, *53*(29), H239. https://doi.org/10.1364/ao.53.00h239

Mustafa, F. M., Toba, M., & Barakat, T. M. (2019). New Simulation of Fiber Bragg Grating: Maximum Reflectivity and Narrow Bandwidth without Side Lobes. In *International Journal of Applied Engineering Research* (Vol. 14, Issue 11). http://www.ripublication.com

Naim, N. F., Maslizan Sudin, S. N., Sarnin, S. S., Ya'acob, N., & Supian, L. S. (2020). Design of fiber bragg grating (FBG) temperature sensor based on optical frequency domain reflectometer (OFDR). *International Journal of Electrical and Computer Engineering*, *10*(3), 3158–3165. https://doi.org/10.11591/ijece.v10i3.pp3158-3165

Ramadhan, K., Saktioto, T. (2021). Integrasi Chirping dan Apodisasi Bahan TOPAS untuk Peningkatan Kinerja Sensor Fiber Bragg Grating. *Komunikasi Fisika Indonesia, 18(2), 111-123*.doi:https://doi.org/10.31258/jkfi.18.2.111-123

Ranathive, S., Vinoth Kumar, K., Rashed, A. N. Z., Tabbour, M. S. F., & Sundararajan, T. V. P. (2019). Performance Signature of Optical Fiber Communications Dispersion Compensation Techniques for the Control of Dispersion Management. *Journal of Optical Communications*. https://doi.org/10.1515/joc-2019-0021

Saktioto, T., Ramadhan, K., Soerbakti, Y., Irawan, D., & Okfalisa. (2021). Apodization sensor performance for TOPAS fiber Bragg grating. *Telkomnika*, *19*(6). https://doi.org/http://dx.doi.org/10.12928/telkomnika.v19i6.21669

Saktioto, T., Ramadhan, K., Soerbakti, Y., Irawan, D., Okfalisa. (2021). Integration of Chirping and Apodization of TOPAS Materials for Improving the Performance of Fiber Bragg Grating Sensors. *Journal of Physics: Conference Series,* 2049, 012001. https://doi.org/10.1088/1742-6596/2049/1/012001

Sayed, A. F., Barakat, T. M., & Ali, I. A. (2017). A novel dispersion compensation model using an efficient CFBG reflectors for WDM optical networks. *International Journal of Microwave and Optical Technology*, *12*(3), 230–238.

Sayed, A. F., Mustafa, F. M., Khalaf, A. A. M., & Aly, M. H. (2020). An enhanced WDM optical communication system using a cascaded fiber Bragg grating. *Optical and Quantum Electronics*, *52*(3). https://doi.org/10.1007/s11082-020-02305-9

Sayed, A. F., Mustafa, F. M., Khalaf, A. A. M., & Aly, M. H. (2021). Symmetrical and post dispersion compensation in WDM optical communication systems. *Optical and Quantum Electronics*, *53*(1). https://doi.org/10.1007/s11082-020-02663-4

Syahfira, V., Permana, N. K., Susilawati, S., Azhar, A. (2021). Penerapan model pembelajaran inkuiri terbimbing untuk penguasaan konsep IPA siswa pada materi cahaya dan optik. *Indonesian Journal Education and Learning,* 5(1), 16-23. http://dx.doi.org/10.31002/ijel.v5i1.4560

Tahhan, S. R., Abass, A. K., & Ali, M. H. (2018).

Characteristics of chirped fiber bragg grating dispersion compensator utilizing two apodization profiles. *Journal of Communications*, *13*(3), 108–113. https://doi.org/10.12720/jcm.13.3.108-113