16 Channels WDM Radio Over Fiber System With DCF and FBG compensators

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Abstract—**In the current telecommunications system design, Radio over Fiber (RoF) technologies are essentials to fifth generation (5G) communication networks, which aims to improve the network capacity and the cost efficiency. A 16-channels WDM RoF system was simulated and analyzed for optimum performance using dispersion compensation fiber (DCF) and fiber Bragg grating (FBG) with channel spacings of 100 GHz and 50 GHz, and SMF lengths of 20km and 50km.**

Keywords: RoF, WDM, Dispersion compensation, Fiber Bragg Grating (FBG), Dispersion Compensation Fiber (DCF).

I. INTRODUCTION

In the current telecommunications system design, Radio over Fiber (RoF) technologies are essentials to fifth generation (5G) communication networks, which aims to improve the network capacity and the cost efficiency. One of the potential solutions is radio-over-fiber (RoF) [1], [2], [3], [4], [5] technology combined with wavelength division multiplexing (WDM) [6], [7]. WDM networks may broadcast several signals with various wavelengths at the same time. Multiple signals from various users with different wavelengths are multiplexed in these networks. However, when the number of users rises, the combination of optical fibers and wireless communications has non-linear effects. As a result, signal noise, undesired frequencies, weak signal quality, and increased latency are introduced.

In this work, a 16-channels WDM RoF system was simulated and analyzed for optimum performance using dispersion compensation fiber (DCF) and fiber Bragg grating (FBG) with channel spacings of 100 GHz and 50 GHz, and SMF lengths of 20km and 50km.

The paper is structured as follows. Section 2 gives a simple model of a WDM Rof system. Section 3 discusses dispersion compensating methods based on DCF and FBG. The simulation results are presented in Section 4. Section 5 concludes the paper.

II. WDM RoF SYSTEM MODEL

The integration of RoF and WDM technologies increases cellular communication system availability. Distinct wavelengths transport different signals in WDM, and they are transmitted over a single fiber. As a result, different wavelength signals are mixed and transmitted via a single optical fibre before being split at the receiver. This results in a higher data rate, more system capacity, greater flexibility, cheaper costs, and a simpler network design, all of which contribute to an enhanced optical communication system.

Figure 1 depicts a simple WDM RoF system. The electrical data is sent into the transmitter (CS), which is composed of an RF modulator, a continuous wave (CW) laser, and an MZM modulator. The data is subsequently routed through the WDM multiplexer. The WDM multiplexer then combines all of these wavelengths and transmits them to the WDM demultiplexer via optical fibre. During reception, all wavelengths are separated and delivered to the receiver (BS), which is primarily made up of a photodiode and a filter.

III. COMPENSATION METHODS BASED ON DCF AND FBG

Light moves slower in a medium than it does in a vacuum. The refractive index of the medium determines the speed at which light travels. Therefore, the transmitted wavelengths travel at different rates across the fiber. Although laser sources are spectrally narrow, they are not monochromatic. This signifies that the input pulse comprises many

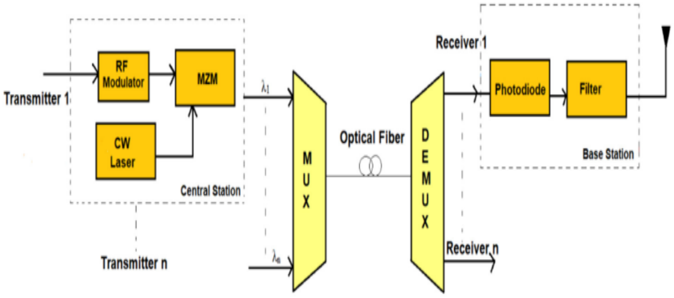


Figure 1: WDM RoF system.

wavelength components that travel at various rates, causing the pulse to spread. This phenomena corresponds to the fiber's chromatic dispersion (Figure 2.

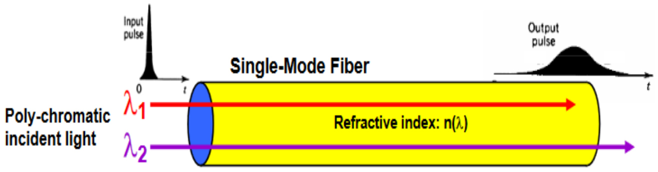


Figure 2: Fiber's chromatic dispersion.

The chromatic dispersion (D) is expressed in ps/nm.km and is determined using equation (1) [8].

$$D = \frac{d}{d\lambda}(\frac{1}{\upsilon_g}) = \frac{-2\pi c}{\lambda^2}\beta_2 \tag{1}$$

Where: λ represents the operative wavelength, υ_g corresponds to the group velocity, c is the optical signal velocity and (β_2) is the group velocity dispersion given by equation (2).

$$\beta_2 = \frac{d^2\beta}{d\omega^2} \tag{2}$$

Where: (ω) is the angular frequency [9].

Many approaches, including dispersion compensation fiber, fiber Bragg grating (FBG), imaged phased array, and planar waveguide technology, have recently been employed to compensate dispersion in optical fiber communication systems. Dispersion compensating fiber (DCF) is a simple and effective way for making efficient installed single mode fiber (SMF) lines. It exhibits a negative dispersion of group velocity ranging from (-70) to (-90) ps/nm.km. This is used to adjust the dispersion in a single mode fiber, which exhibits positive group velocity dispersion at the laser wavelength source of 1.55 μm.

Furthermore, the Fiber Bragg Grating periodic structure is ideal for compensating group velocity dispersion for several wavelength variations. FBG is a dynamic dispersion compensator that differs linearly in lengthways of the fiber reflective index outline depending on the manner of area writing on the fiber core. The incident wavelength signals are reflected by the grating assembly based on the Bragg wavelength. The optical signal reflection wavelength will spread a wider distance inside the fiber Bragg grating before reflection, depending on the grating period and the actual refractive index. The Bragg wavelength λ_B is calculated as follows: $\lambda_B = 2n\Lambda$, where n is the refractive index of the fiber core and Λ is the period of the FBG grating. The lower the light wavelength, the shorter the distance traveled inside the grating before reflection. As a result, the light widening caused by group velocity dispersion in typical single mode fiber is compacted by traveling signal inside FBG. As shown in Figure 3, an FBG is composed of a series of parallel semi-reflecting plates separated by Λ.

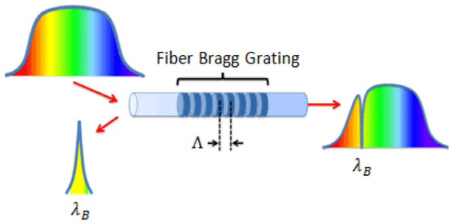
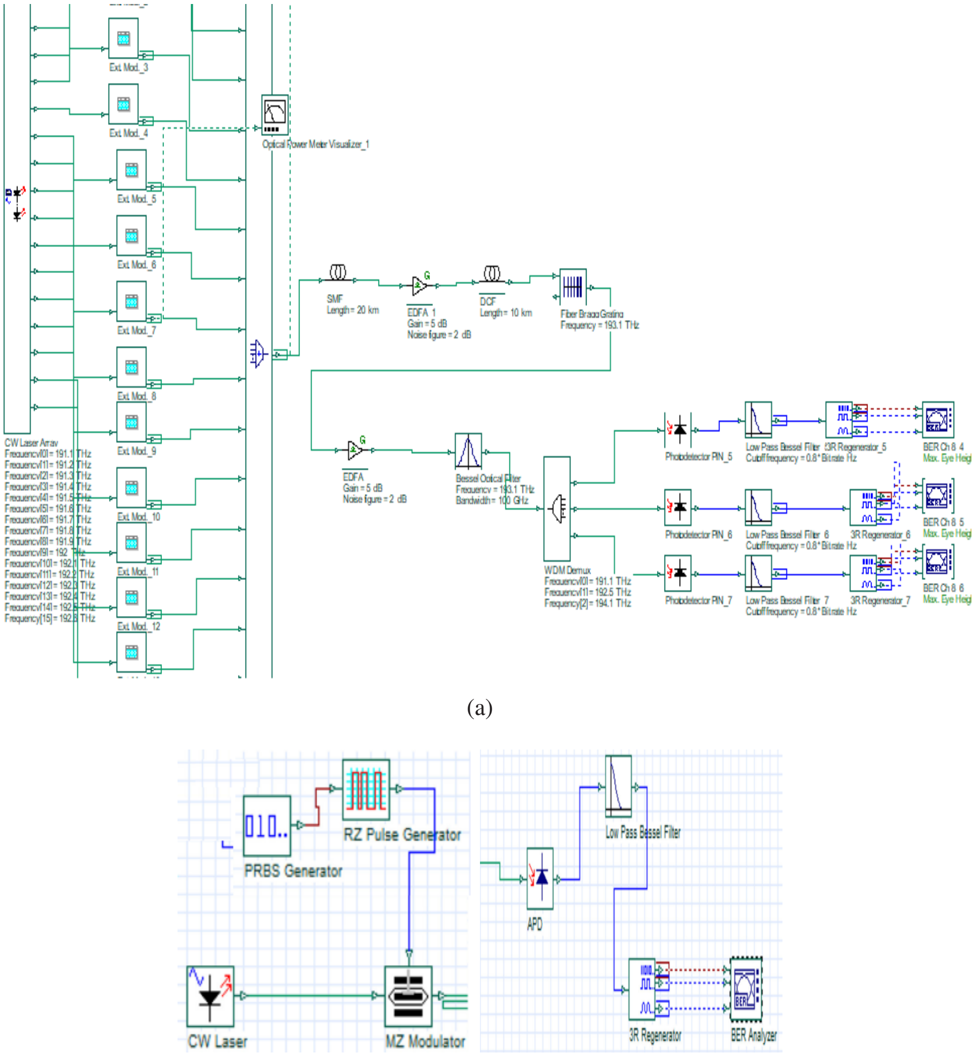


Figure 3: FBG sensor principle

IV. SIMULATION RESULTS

We have designed a 16 channels WDM-RoF system with each channel operating at 10 Gbps, using Optisystem 19. The diagram representing the 16 WDM-RoF system design is illustrated in Figure 4. The transmitter section comprises 16 RF signals that are combined, using a WDM multiplexer, and are transmitted over an SMF fiber.

Using Optisystem 19, we created a 16-channel WDM-RoF system, with each channel working at



(a)

(b)

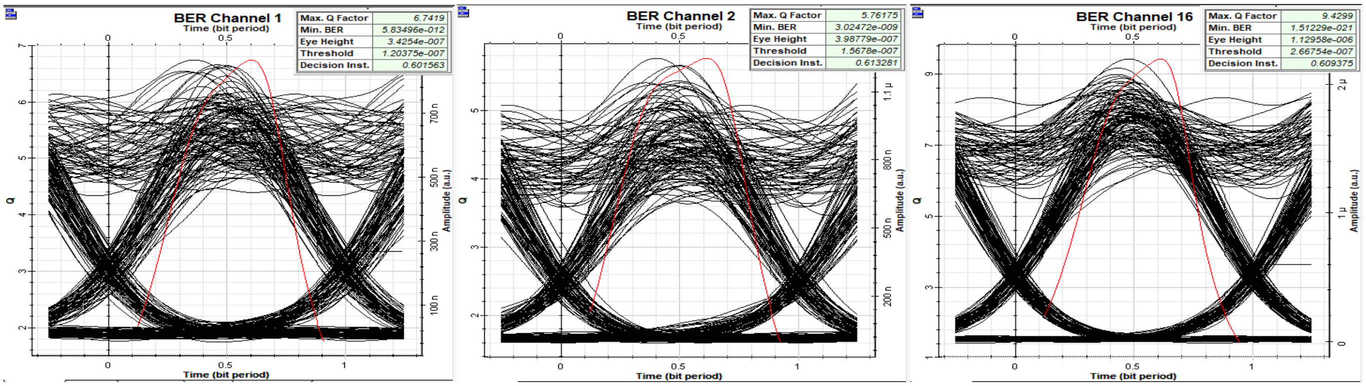
(c)

Figure 4: 16 channels WDM-RoF system.

10 Gbps. Figure 4 shows the considered 16 WDM-RoF system architecture. The transmitter part consists of 16 RF signals that are merged using a WDM multiplexer and sent through an SMF fiber. In order to evaluate the performances of the proposed WDM Rof system, we vary the channel spacing, the SMF fiber length and the transmitter power level. Furthermore, the following performance parameters are taken into account: Quality factor, Minimum Bit Error Rate, and height of eye diagrams.

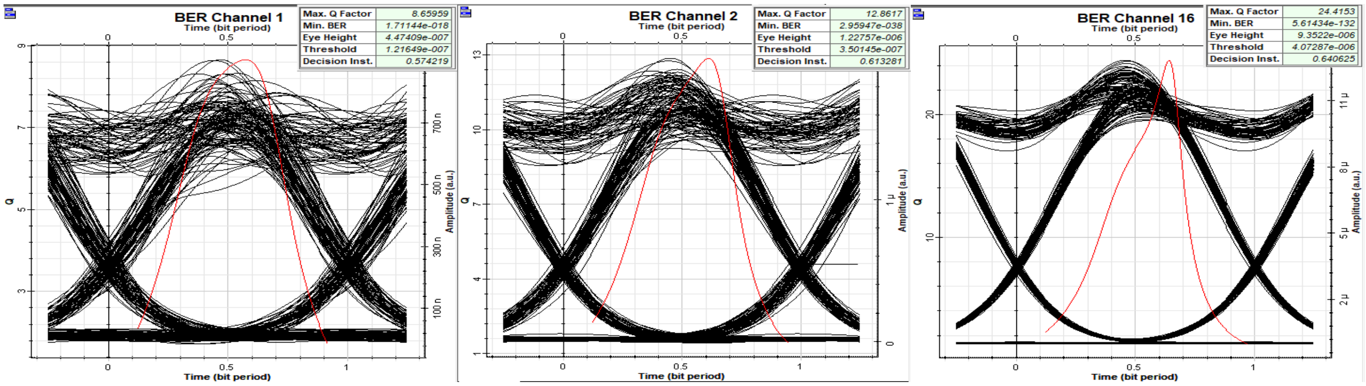
Figure 4 depicts the transmitter architecture. Each transmitter contains a pseudorandom bit sequence (PRBS) generator that generates binary data at a data rate of 10 Gbps and feeds it to a return-to-zero (RZ) pulse generator that generates baseband signals. The RZ coding technique was used because it is more fair to fiber non-linear effects. The Mach-Zehnder modulator (MZM) generates an optical carrier signal with a high frequency using the CW source laser.

By using WDM multiplexer, optical signals of distinct frequencies from all CW lasers are modulated and merged to enhance data transmission capacity. A single mode fiber is used to transmit this multiplexed signal (SMF). The SMF was adopted because, as compared to multimode fiber (MMF), it can transmit optical signals at a greater data rate across a longer distances, even if the optical signal has higher order dispersion and non-linearities, which may restrict the transmission distance.



(a) (b) (c)

Figure 5: Eye diagrams for WDM RoF system for 50 GHz channel spacing, SMF length 20 km, power level 0dBm.



(a) (b) (c)

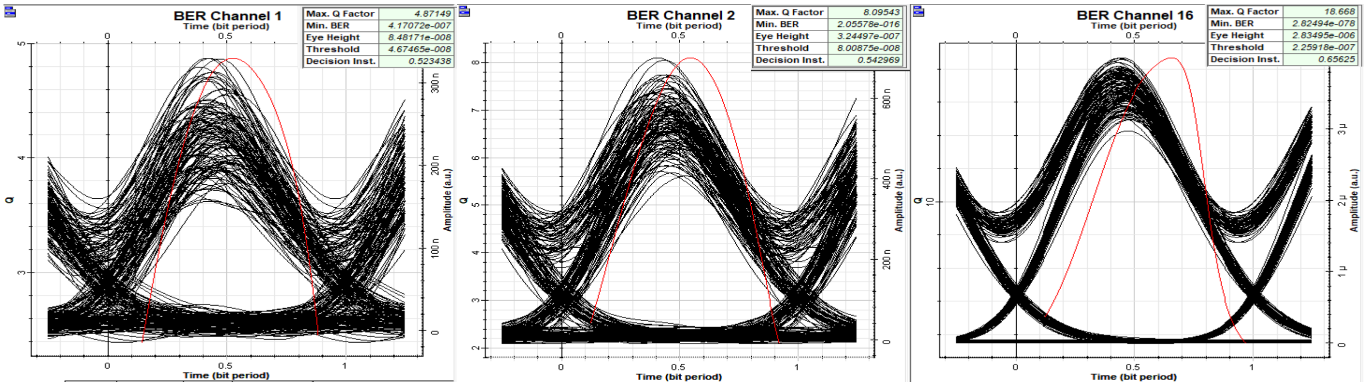
Figure 6: Eye diagrams for WDM RoF system for 100 GHz channel spacing and SMF length 20 km, power level 0dBm.

The erbium-doped fiber amplifier (EDFA) serves as an in-line amplifier and is positioned after the SMF. In order to compensate transmission losses, the EDFA amplifies the weak input signal and enhances it to a certain level.

DCF and FBG are also utilized in network system design to compensate for connection losses and dispersion effects. DCF is applied to the amplified signal. In this situation, the DCF provides dispersion equals to 80 ps/nm/km, permitting the chromatic dispersion to be lowered to near zero. FBGs are formed by exposing the fiber core to extremely strong UV rays. This raises the refractive index of the fiber core, resulting in a fixed modulation index known as "grating". This setup makes use of a low-cost filter to decrease chromatic dispersion while also functioning as a wavelength selector.

Figure 4 depicts an avalanche photodiode detector (APD) for optical to electrical conversion, a low-pass Bessel filter for noise reduction, a 3R regenerator for regenerating an original electrical signal, and a BER analyzer for viewing the outputs. Table I shows the simulation parameters used in the proposed layout.

Figures 5 and 6 illustrate the obtained eye diagrams for the three channels 1,8, and 16, when the SMF length is fixed to 20 km , the transmitter power level is set to 0 dBm, and the channel spacing ranges from 50Ghz to 100Ghz. As we can see, the quality factor and BER values for the channel spacing of 100Ghz are improved compared to a channel spacing of 50Ghz . For channel 1, the quality factor



(a) (b) (c)

Figure 7: Eye diagrams for WDM RoF system for 100 GHz channel spacing, SMF length 50km, power level 0dBm.

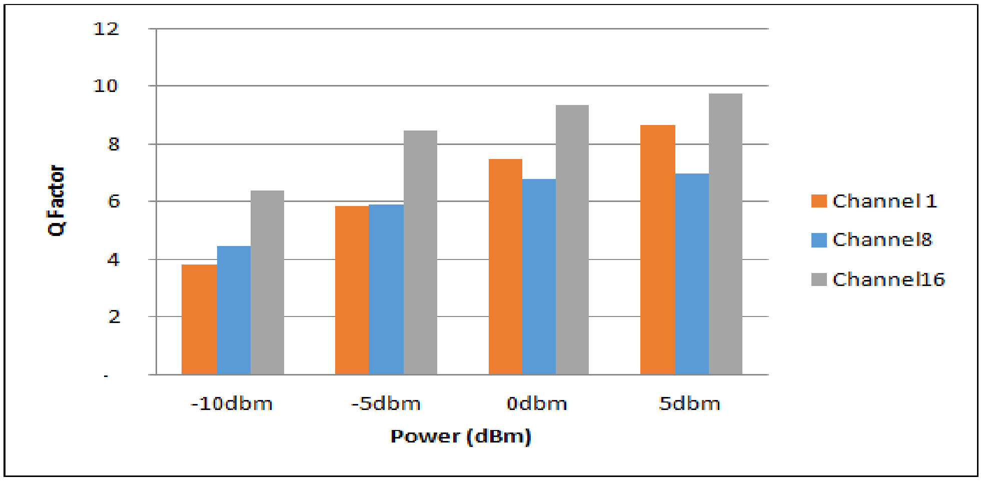


Figure 8: Q factor variation with power at channel spacing of 50Ghz.

Table I: Simulation Parameters

Parameters	Value
Bit rate of PRBS	10 (Gbits/s)
Sequence length	64
Samples / bit	256
Power of CW laser	5 (dBm)
Channel spacing	100 (Ghz)
Frequency of CW laser	193.1–194.6 (THz)
SMF length	10 (km)
SMF dispersion	16 (ps/nm/km)
EDFA Gain	25 (dB)
DCF length	10 (km)
DCF dispersion	−80 (ps/nm/km)
FBG length	2 (mm)

increases from 6.74 to 8.65 while the BER decreases from 5.83e-012 to 1.71e-018 for channel spacings of 50 and 100 GHz, respectively.

Figures 6 and 7 depict the obtained eye diagrams for the three channels 1,8 and 16, when varying the SMF length from 20km to 50km and fixing the channel spacing to 100 Ghz and the transmitter power level to 0 dBm. We observe that as the SMF length increases, the quality factor and BER values decrease dramatically. For SMF lengths of 20km and 50km, respectively, the quality factor falls from 8.65 to 4.87 and the BER rises from 1.71e-018 to 4.17e-07.

Figure 8 represents a bar chart, showing the

Q factor variation for the three channels 1,8 and 16, according to the power variation from -10dBm to 5dBm at channel spacing of 50 Ghz. When the power is reduced, the quality factor decreases accordingly. For channel 1, the quality factor rises from 3.80 to 8.64 for power levels of -10dBm and 5dBm, respectively. The variation of BER with transmitter power is seen in Figure 9. When we increase the transmitter power, we see that the BER values decrease.

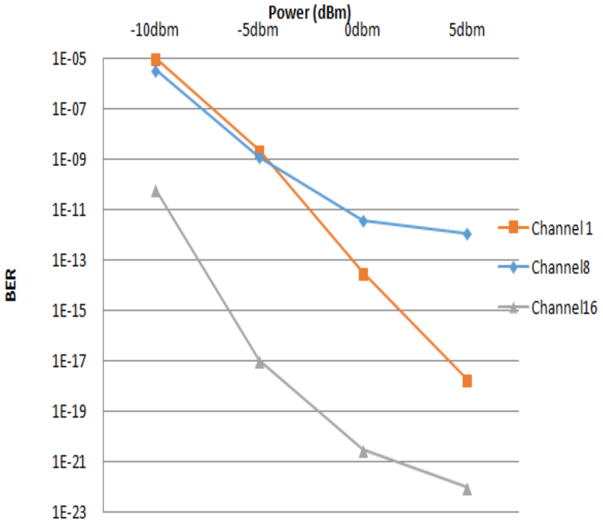


Figure 9: BER variation with power at channel spacing of 50Ghz.

V. CONCLUSIONS

In this paper, we used Optisystem to simulate a 16-channel WDM Rof system. We examined dispersion compensation fibre (DCF) and fibre Bragg grating (FBG) with channel spacings of 100 GHz and 50 GHz, variable input power levels of 0 and 5 dBm, and SMF lengths of 20km and 50km in the suggested design. The Q factor, BER parameters, and height of eye diagrams are used to examine and compare the simulation results. We concluded that increasing channel spacing and transmission power increases the Q factor, but increasing SMF length reduces it. As a perspective, we will investigate the best BER performance of the proposed WDM-RoF system.

REFERENCES

[1] D. Che, “Analog vs digital radio-over-fiber: A spectral efficiency debate from the snr perspective,” *Journal of Lightwave Technology*, vol. 39, no. 16, pp. 5325–5335, 2021.

[2] M. U. Hadi, H. Jung, S. Ghaffar, P. A. Traverso, and G. Tartarini, “Optimized digital radio over fiber system for medium range communication,” *Optics Communications*, vol. 443, pp. 177–185, 2019.

[3] X. Liu, “Chapter 5 - digital signal processing–assisted radio-over-fiber,” in *Optical Communications in the 5G Era* (X. Liu, ed.), pp. 103–132, Academic Press, 2022.

[4] L. P. Barry, A. Delmade, D. Dass, and C. Browning, “Role of analogue radio-over-fibre technology beyond 5g,” in *Optical Fiber Communication Conference (OFC) 2022*, p. Th1I.1, Optica Publishing Group, 2022.

[5] S. Ishimura, H. Takahashi, R. Inohara, K. Nishimura, T. Tsuritani, and M. Suzuki, “High-capacity and high-fidelity analog radio-over-fiber mobile fronthaul,” in *Metro and Data Center Optical Networks and Short-Reach Links V* (A. K. Srivastava, M. Glick, and Y. Akasaka, eds.), vol. 12027, pp. 119 – 122, International Society for Optics and Photonics, SPIE, 2022.

[6] R. Bhattacharjee, P. Dey, and A. Saha, “Implementation of an enhanced 32 channel 256 gbps dwdm based radio over fiber optical system for constricted channel spacing employing fiber bragg grating,” *Optik*, vol. 253, p. 168598, 2022.

[7] H. J. Kbashi, V. Sharma, and S. Sergeyev, “Dual-wavelength fiber-laser-based transmission of millimeter waves for 5g-supported radio-over-fiber (rof) links,” *Optical Fiber Technology*, vol. 65, p. 102588, 2021.

[8] *Optical Fibers*, ch. 2, pp. 21–65. John Wiley & Sons, Ltd, 2021.

[9] G. Gnanagurunathan and F. Rahman, “Comparing fbg and dcf as dispersion in the long haul narrowband wdm systems,” in *2006 IFIP International Conference on Wireless and Optical Communications Networks*, pp. 4 pp.–4, 2006.