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Implementation of Symmetrical Compensation based DWDM RoF system Toward Tbps of data transmission for 5G Fiber Optic Networks

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***Abstract*— There are various benefits to using a Dense Wavelength Division Multiplexing Radio over Fiber (DWDM-RoF) technology in 5G communication networks, including increased capacity and data rate, as well as a reduction in the cost of operation. This is why many researchers start developing systems and approaches to achieve the best income. In this paper, it has been designed a 32-channel DWDM RoF system to handle efficient 1.28 Tbps data rate transmission by using a hybrid approach of compensation techniques. Three cases of frequency spacing (100,150,200) GHz were included in the system performance investigation. Additionally, different modulation formats are studied to handle the most reliable method to be utilized in the future. Results are obtained concerning Quality Factor (QF) and Bit Error Rate (BER) parameters are analyzed, and compared with the previous system. Such results indicate a significant impact of using the symmetrical hybrid compensation in boosting the parameters result for the proposed system. Where when using The Non-Return to Zero (NRZ) the achieved averaged QF parameter values were (20.89, 15.60, 12.69, 10.46) dBm for the distances of (60, 120, 180, and 240) km respectively. Meanwhile, the BER values were ($2.43*10^{-80}$, $2.85*10^{-29}$, $1.09*10^{-18}$, $7.61*10^{-11}$) for the same subset of studied distances respectively. Meanwhile, when handling the proposed system with the RZ modulation method the values are further improved.**

Keywords— DWDM, RoF, Dispersion, Quality Factor, BER, Eye diagram

I. INTRODUCTION

Fiber-optic communication is a means of delivering light pulses across an optical fiber to send data from one location to another. The light is modified to carry information and produces an electromagnetic carrier wave. The worldwide development and deployment of light wave systems are being driven by the potential bandwidth of optical communication networks [1]. It will be necessary to interconnect large numbers of cells and microcells due to the introduction of significant quantities of microcells. This can be accomplished efficiently by utilizing optical fiber, which has a high transmission capacity at a cheap cost and can be installed quickly [2]. This is done with the use of Dense Wavelength Division Multiplexing (DWDM) and Radio over Fiber (RoF) based system. Several advantages of RoF systems are represented by increased capacity, lower cost, easier installation, lower power consumption, and improved coverage for microcells. RoF is a technology that provides the ability to increase bandwidth at a reasonable cost, and this concept has emerged as a suitable topic for a large number of research studies [3,4]. Orthogonal Frequency Division Multiplexing (OFDM) has been widely utilized in wireless communication because it offers lower Inter Symbol Interference (ISI), lower computational complexity, and more robustness when compared to alternative multiplexing techniques. OFDM has dominated in wireless broadcast systems like Wi-Fi and WiMAX because of its robustness to multipath fading and high sub-carrier density [5].

Like other communication systems, optical communication suffers from issues such as dispersion, attenuation, and non-linear effects, all of which degrade performance. Dispersion has the greatest impact on the system and is more difficult to overcome than the other two issues [6]. As a result, it's critical to develop an effective dispersion correction technique that improves the optical system's performance. The most critical aspect of an optical fiber communication system is Dispersion Compensation, since, without it, pulse spreading occurs, causing output pulses to overlap. The output data will become indiscernible if an input pulse is caused to spread to the point where the rate of change of the input exceeds the fiber's dispersion limit [7]. As a result, the utilization of the most reliable compensation method is very significant in handling a transmission system with higher capacity and far-distance transmission. As a result, in this paper, a symmetrical compensation is designed and implemented for 32 DWDM channels to handle the transmission of 1.28 Tbps of data rate for distances up to 240 km. This system implementation aims to design a reliable system that boosts its performance by using a hybrid compensation technique and analyzing system performance concerning different modulation formats and channel spacing.

II. RELATED WORK

Several improvements for fiber optic communication-based systems were proposed to improve performance and handle greater data rates. For example, in [8], the author suggested a WDM RoF system with only two channels and no compensatory mechanism. The data rate was 1 Gbps across a distance of 50 kilometers (km) utilizing NRZ modulation. They have been testing the system with single-mode and multimode Mack Zander Modular (MZM) to see how it performs. However, the system's data rates and utilization distances remain modest. A 16 DWDM Sub Carrier Modulation (SCM) based system with 28.8 Gbps total data throughput, 150 km transmission distance, and NRZ architecture was also presented in [9]. Their work does not describe remuneration. Their technology uses an Erbium-Doped Fiber Amplifier (EDFA) to increase the transmitted signal and improve the receiving signal. Also, the amplifier's power was used after the system's transmission. Data speeds must be enhanced even with amplifiers, specifically by employing another optical detector technology rather than the APD.

Another system in [10] claimed to handle 4 WDM RoF channels at a 60 km distance and 4 Gbps data rate. The suggested system uses a reduced bandwidth and narrower channel spacing of 50 GHz. Using such spacing, however, limits planned system capacity and transmission performance. A system of two channels with a distance of 30 km was also proposed using NRZ modulation. It neither uses compensation nor specifies the attained data rate. The suggested system adjusts the MZM Extension Ratio

(ER) to improve the received signal quality [11]. Changing ER does not directly enhance system performance. In addition, [12] investigated both the NRZ and RZ formats for a 10-channel WDM RoF system capable of handling a 10 Gbps data rate. NRZ outperforms RZ when used with an APD detector at the receiver. However, they have compared the two modulations for a shorter distance of 70 km, with no compensating approach. Authors in [13] proposed a 960 Gbps DWDM RoF system with 80 channels. The modulation type employed is RZ with post-compensation. With their proposed system, they used Roman Optical Amplifier (ROA) power and studied alternative channel spacing between (20 to 100) GHz, with the idea that higher is better. Even though the system could manage high channels, it had issues handling data rate per channel, and distance was an issue that was not addressed in their study. In addition to that, other authors in [14] presented a 25-channel DWDM RoF system for 1 Tbps data throughput and 180 km distance. The system was built and tested for both NRZ and RZ, with NRZ being preferred. However, due to sample leakage, only two of the 25 channels were used for performance analysis based on the eye pattern-based parameter.

Recent efforts provided by authors in [15] designed a 16-channel DWDM RoF system using optisystem software with NRZ modulation format for only 60 km transmission. The compensatory method employed was Fiber Bragg Grating (FBG). The system could handle 160 Gbps and researchers found that employing lower power for dependable transmission is better. The current allocation of 5G communication has hampered the data rate achieved by FBG. Other researchers in [16] constructed a 16- channel DWDM RoF system with a 180 km distance and 640 Gbps data throughput utilizing post compensation. Another system with 32 channels and a 1.28 Tbps data rate was presented in [17]. NRZ modulation uses little input power. A major way of handling high data rate estimation was found. The 180 km results were too near to the threshold and need to be improved. Also, in [18], a 32-channel DWDM RoF system was proposed employing the FBG with a post-compensation approach. The QF-based parameter optimal result was around 16 dBm. However, the acquired data rate (256 Gbps) needs to be enhanced, as well as the distance (more than 120 km) and channel spacing.

As a motivation from these previous studies, this paper offers a 32-channel DWDM RoF system and obtains the power of the symmetrical Compensation for Dispersion Compensation Fiber (DCF) technique. Investigating the impact of NRZ and RZ modulation formats is included to increase transmission distance. Analyzing results would be based on the performance of the obtained QF and BER results for the suggested system involves studying various channel spacing, modulation schemes, and distances. The rest of the paper is organized as follows: Section 3 of the paper describes the approach to the proposed system. Section 4 explains the proposed system. Then comes section 5 with the analysis of the results, and section 6 which is the conclusion.

III. METHODOLOGY

This section will describe the related theoretical concepts and techniques forming the proposed system.

A. DWDM

A technique for increasing the bandwidth of existing fiber networks by Combining data signals from many sources via a single pair of optical fiber while retaining perfect separation between the data streams is the goal of this technique. Optical Fiber cables (OF cables) are increasingly and extensively used as the backbone of carriers' interoffice networks, serving as the industry standard for telecommunications infrastructure [19]. Due to the creation of numerous virtual fibers, DWDM allows for massive volumes of data to be transmitted across a single network link, hence dramatically increasing the capacity of the physical medium. Because of its ability to handle large amounts of data, DWDM is widely used by telecommunications and cable providers alike. The network is a critical component of their core networks. Furthermore, it is an excellent choice for anyone who operates heavily packed data centers. DWDM has a smaller wavelength gap, which allows for more channels to be packed onto a single fiber [20]. It performs best in systems with more than eight active wavelengths per fiber. Additionally, an array of infrared laser beams can be used to create the channels if desired. Each channel can carry 100 Gbps, with a total of 192 channels per fiber pair, resulting in a total capacity of 19.2 terabits per second per pair. In part, because the channels are physically distinct and do not interact with one another due to the physical qualities of light, each channel may support a variety of different data formats and transmit at a variety of different data rates [21]. Fig. 1 is a generic scheme design that demonstrates this concept in considerable detail.

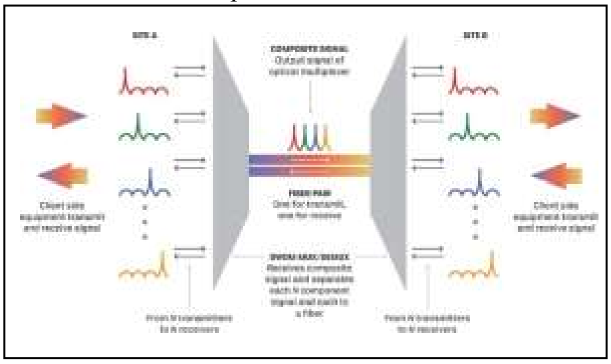


Fig. 1. DWDM concept [21].

B. RoF

The use of optical fiber lines to distribute radio frequency signals from a central point (head-end) to Remote Antenna Units is referred to as Radio over Fiber (RoF) technology. Broadband communication systems and WLANs execute RF signal processing activities such as frequency up-conversion, carrier modulation, and multiplexing, which are then delivered directly into the antenna by the base station or the Radio Access Point (RAP). As illustrated in Fig. 2, RoF allows for the consolidation of RF signal processing functions in a single shared location (head end), followed by the use of optical fiber, which has a low signal loss (0.3 dB/km for 1550 nm wavelengths and 0.5 dB/km for 1310 nm wavelengths), to distribute the RF signals to the Remote unit of the antenna [21]

C. Dispersion Compensation Technique

The term "dispersion" refers to the spreading of pulses in an optical cable. It is caused by factors such as the numerical aperture, core diameter, refractive index profile, wavelength, and laser linewidth that cause the pulse to expand as it propagates through the fiber. The amount of dispersion rises as the length of the fiber grows. Inter Symbol Interference (ISI) is the term used to describe the total effect of dispersion on the operation of a fiber optic system. When the pulse spreading induced by dispersion causes the output pulses of a system to overlap, ISI develops, and the system becomes invisible. Dispersion can be classified into three types: modal dispersion, chromatic dispersion, and polarization mode dispersion. Modal dispersion is the most common type of dispersion. [6]

Dispersion compensation is the most significant characteristic necessary in an optical fiber communication system to eliminate the spreading of optical or light pulses. It is also the most difficult to implement. A DCF is a loop of fiber with negative dispersion equal to the dispersion of the transmitting fiber, and it is used to transmit data. It can be put between two optical amplifiers. Either the beginning (pre-compensation techniques) or the end (post-compensation techniques) of the signal path. However, it results in a huge footprint and insertion losses. In addition, there is a third method of executing compensation known as symmetrical compensation, which is located in the middle of the other two [6]. Fig. 2 depicts the overall concept of deploying transmission components to build the three categories of transmission components. [21].

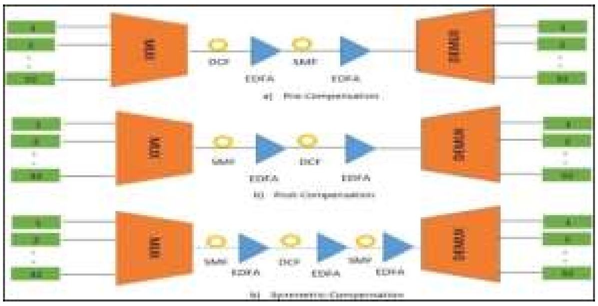


Fig. 2. The three types of Dispersion based compensation techniques implementation [21]

IV. PROPOSED SYSTEM

In this section, the proposed system is described in detail as it consists of three parts. The view of the total designed system by using optisystem software can be seen in Fig. 3. And the schematic view of the proposed system can be illustrated in Fig. 4. The first part, the transmitter part consists of a WDM transmitter with 32 channels which internally includes the components of a bit sequence generator with the data rate of 40 Gbps, a pulse generator of NRZ, MZM as a modulator, and the laser source component with lunched power of 0 dBm and frequency starts with 190 THz and a selected spacing between the wavelength of 200 GHz. Also, the WDM transmitter is followed by a Multiplexer (Mux) device with the same number of channels to handle the mission of combining the signals in a single link to be transmitted over a Fiber Optic (FO) cable in the next part. A close look at this part can be seen in Fig. 5. The second part, the transmission system will be formed by the utilization of FO cable with the type of Single-Mode Fiber (SMF) with a length of 25 km and DCF component with a length of 10 km, which is used to handle the problem of Chromatic Dispersion (DC) than happed in this section. Also, an amplifier of the type of Erbium-Doped is used in this section with a gain of 5 dB and a noise figure of 6 dB. The power of the proposed system implemented in this part is represented by utilizing the DCF compensation technique of the symmetrical type which could achieve the optimum results due to the formulation and distribution of the components as seen in Fig. 6. Furthermore, the distance for investigation is controlled by using loop control, wherein each iteration would achieve a total of 60 km.

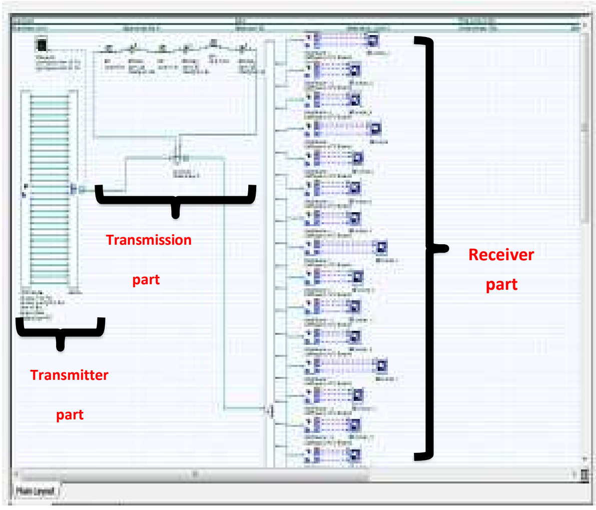


Fig. 3. the total system designed using the Optisystem simulator

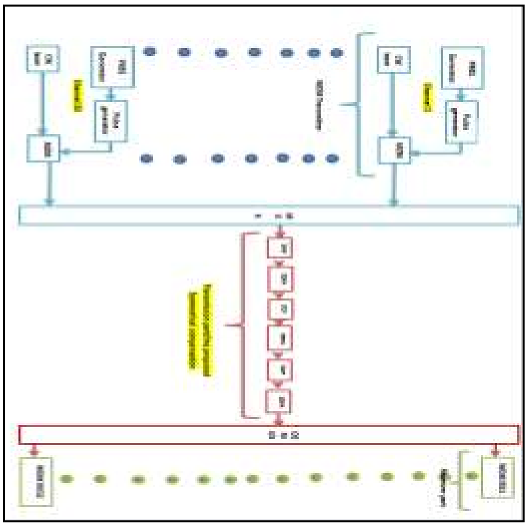


Fig. 4. The schematic view of the proposed system

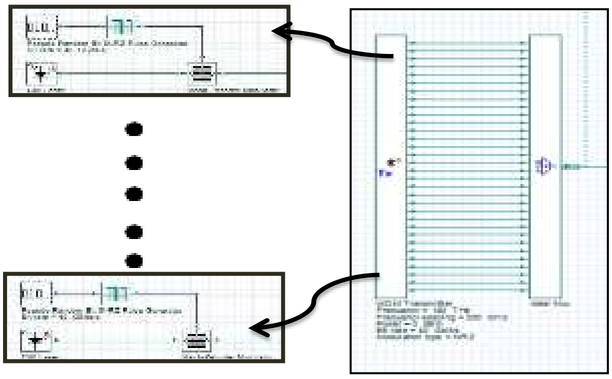


Fig. 5. The first part of the implemented system.

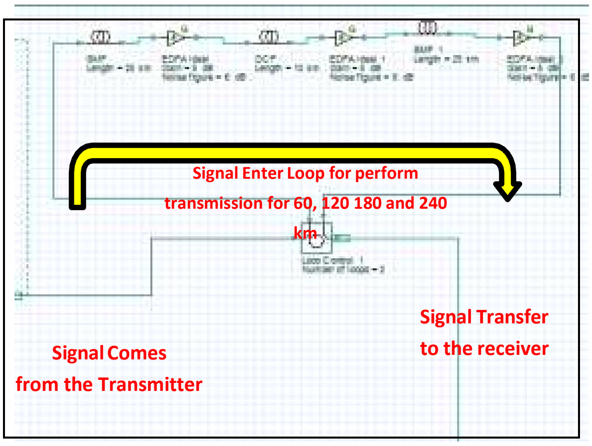


Fig. 6. The second part with the symmetrical based method

Finally, the third part is represented by the receiver part which starts with using the Demultiplexer device which separates the transmitted optical signal from the previous part and distributes it into 32 receiver channels then each channel is essential with a WDM receiver which internally consists of a Photo Detector (PD) component with the type of PIN to convert the optical signal into electrical, filter device, 3R generator and finally the BER analyzer tool used to visualize the results to be obtained. The demonstration of this part in the optisystem is seen in Fig. 7. Finally, all the other parameters selected for the proposed system were listed in Table I

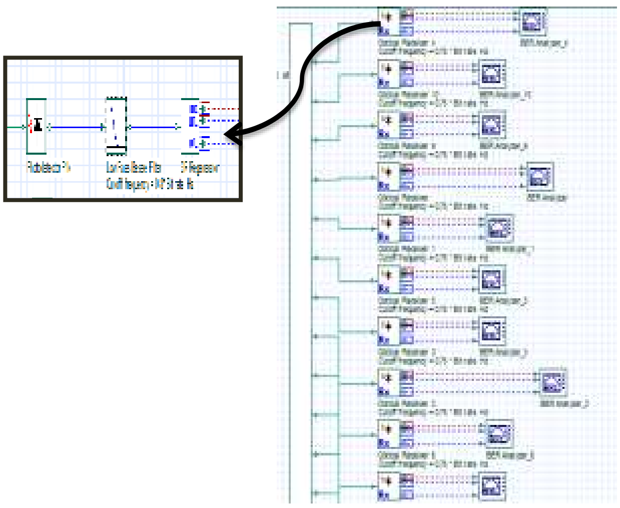


Fig. 7. Receiver part of the system

Table I. Overview of the most significant parameters set with the proposed system

Parameter	Value	Unit
Number of output ports	32	-
Frequency	190	THz
Frequency spacing	200-150-100	GHz
Power	0	dBm
Extinction ratio	30	dB
Bit rate	40	Gbit/s
Modulation type	NRZ-RZ	-
Length (SMF)	25	km

V. RESULTS ANF DISCUSSION

This section clarifies and analyzes the results obtained from the proposed DWDM RoF system-based symmetrical compensation.

A. Proposed system results

The results for the proposed 32-channel system which has been described previously would be analyzed based on the studied parameters of QF and BER and for all the tested 32 channels. The performance analysis of the system would handle the transmission distance of (60,120,180 and 240) km. Such results have been recorded and analyzed as seen in Fig. 8 and Fig. 9 for QF and BER parameters respectively.

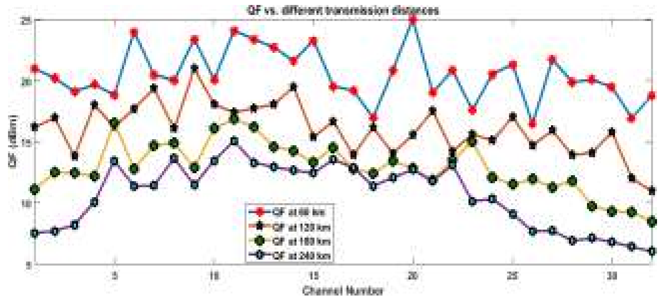


Fig. 8. The relation of QF vs. different transmission distances

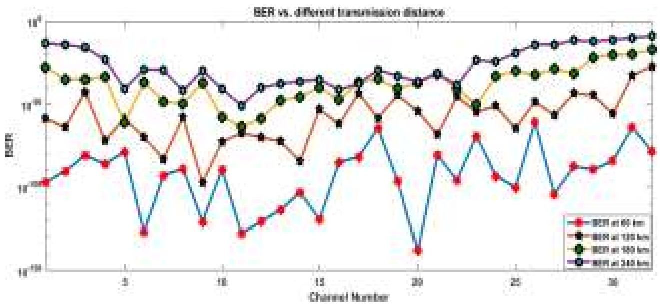


Fig. 9. The relation of BER vs. different transmission distances

From Fig. 8, it can be seen a reversal relation between the raising distance and the QF values and this is due to the greater impact of the attenuation forcing the transmitted signals over a fiber optic medium. It is worth mentioning that the case of 240 km transmission has achieved QF results above the QF minimum threshold of 6 dBm, which indicates the reliability of the proposed system. For the Fig. 9 observations, it can be seen a direct relation as increasing the distance would increase the error in the transmitted bits. Even though increasing the impact of error with transmitted bits but all observed results were above the threshold of E^{-10}. The result that might confirm the reliability of the proposed system as designed is based on using the symmetrical compensation method.

B. Results of different channel spacing

A second observation for the proposed system would be formed by considering three cases of (200, 150, and 100) GHz for channel spacing values between the allocated 32 channels, where a set of sample channels with numbers of (1, 4, 8, 12, 16, 20, 24, 28 and 32) were selected and studied for spacing variation and their effect on the results of QF and BER parameters. These results are shown in Fig. 10 and Fig. 11 respectively. Firstly, Fig. 10 shows a direct relation between channel spacing and QF, as raising the spacing would reduce the channel overlapping and interference and hence improve the QF values. Also, in the same figure, it can be noticed that the difference between the three cases of channel spacing reduced with increasing the distance. Indicating that the key significance of larger spacing is less than 180 km. Secondly, Fig. 11 shows a reverse relation between raising channel spacing and the BER also raising distance would minimize the difference in BER reduction between the three investigated cases. Hence, using the spacing of 200 GHz was confirmed of being optimum for the proposed system.

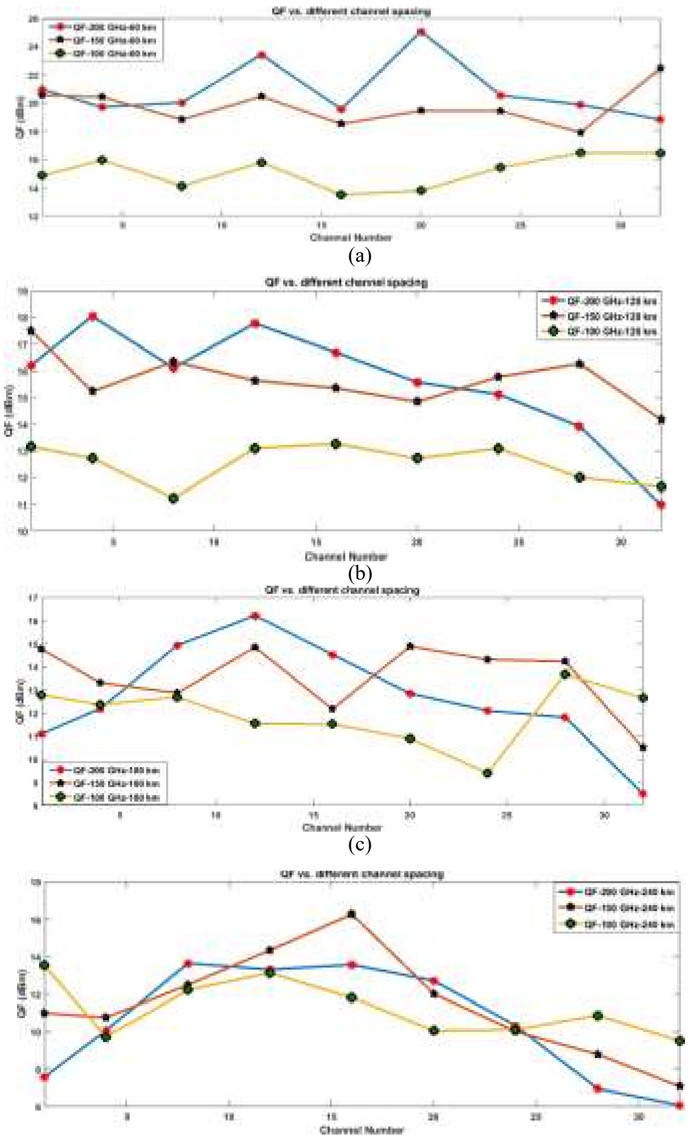
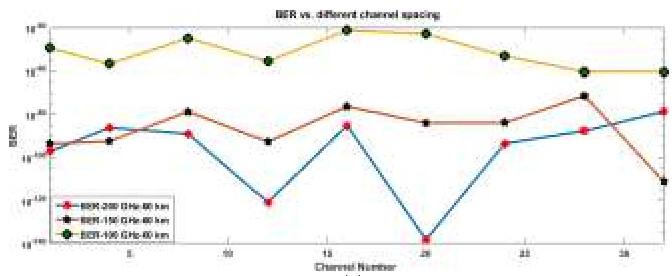


Fig. 10. QF vs. different channel spacing for (a) 60 km, (b) 120 km, (c) 180 km, and (d) 240km.



(a)

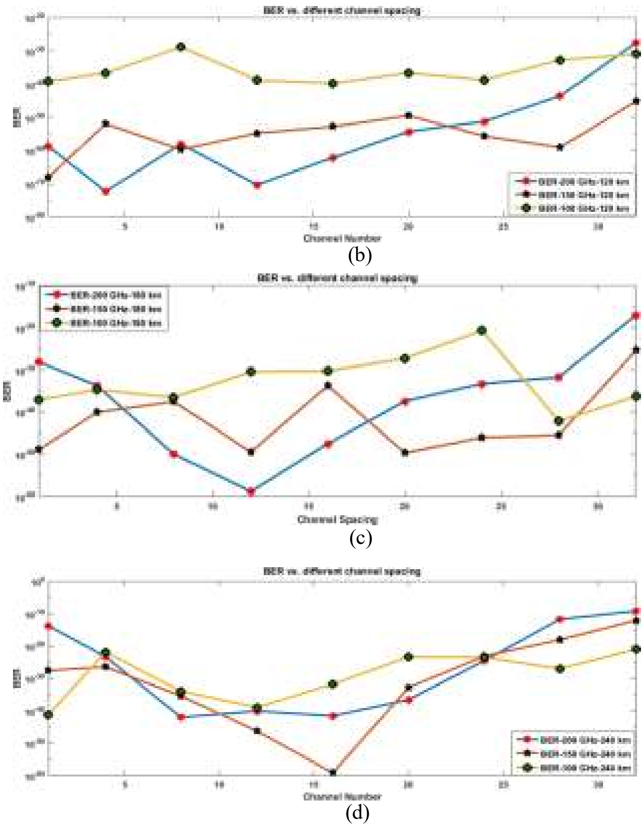


Fig. 11. BER vs. different channel spacing for (a) 60 km, (b) 120 km, (c) 180 km, and (d)240 km.

Addition optimization would be considered and handled by investigating the utilization of different modulation formats represented by the NRZ and RZ. To validate the reliability and impact of each method on the proposed system. Such investigation would be considered concerning the same samples and for the two types per each of the four transmission distances and for the QF and BER parameters as seen in Fig. 12 and Fig. 13 respectively, it can be noticed that using the RZ method for modulation is better in achieving QF and BER results than using the NRZ when handling small distance transmission. And by raising the distance of transmission the variation between the two investigated modulation methods are reduced. Even though, RZ still performed better concerning the proposed system as compared to the NRZ-based system.

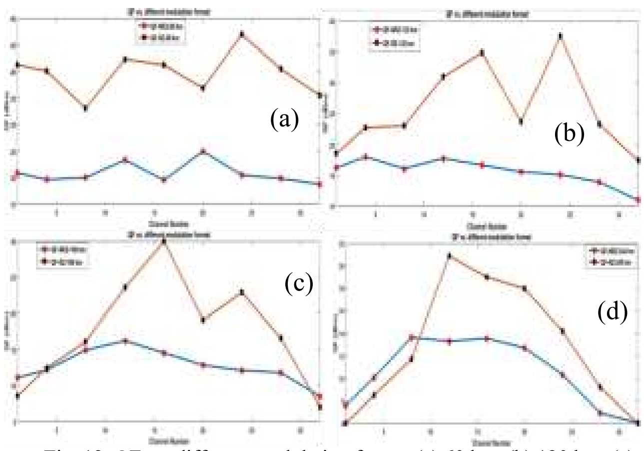


Fig. 12. QF vs. different modulation format (a) 60 km, (b) 120 km, (c) 180 km, and (d) 240 km

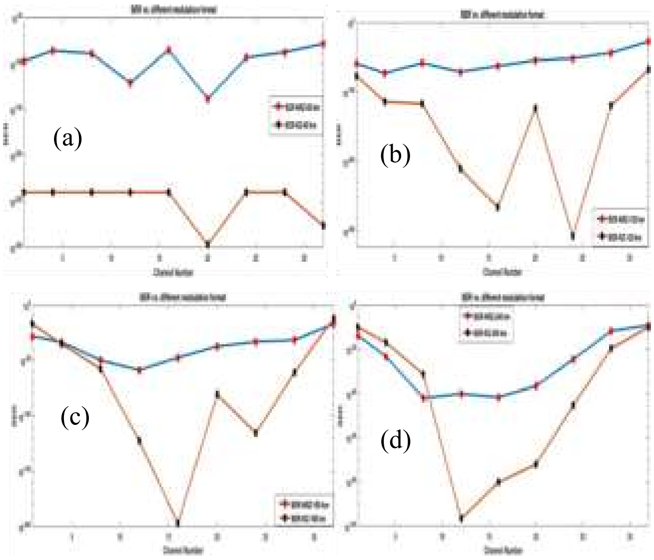


Fig. 13. BER vs. different modulation format (a) 60 km, (b) 120 km, (c) 180 km, and (d) 240 km

VI. CONCLUSION

In this study, a 32-channel DWDM RoF system has been designed to carry 1.28 Tbps of data across 240 km. This investigation used NRZ and RZ modulation formats with 200, 150, and 100 GHz frequency spacing. The suggested symmetrical approach for FO transmission improves QF and BER. Where QF average distances were (20.89, 15.60, 12.69, 10.46) dBm and average BER was ($2.43e^{-80}$, $2.85e^{-29}$, 1.09^{e-18}, 7.61^{e-11}) for (60, 120, 180, and 240) km. Also, research findings suggest employing 150-200 GHz separation for short distances. 100-150 GHz is suggested for distances up to 180 km owing to minimal influence on outcomes. RZ modulation is better than NRZ at short distances, although the differences diminish over longer distances. Using symmetrical compensation might enhance transmission distance from 180 km to 240, according to [16]. The QF findings improved by 5.15, 2.27, and 1.7 dBm for 60, 120, and 180 km compared to the previous release. A future study might combine a symmetrical technique with FBG and explore its performance across other modulation formats.

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