Design and implementation of DP-DQPSK DWDM transmission system by using direct detection

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ABSTRACT

Designing a system that guarantees both the lower cost implantation, lower complexity on the receiver station side and higher data rate was an essential topic for several researchers recently, in which several methods and approaches were proposed to handle these problems individually and with the best overall outcome. In this work, these problems would be considered by designing and analyzing a novel system based on the combination of Dual Polarization Differential Quadrature Phase Shift Keying (DP-DQPSK) and Dense Wavelength Division Multiplexing (DWDM) technique and by using the Direct Detection (DD) technique. The system was designed with Optisystem software 18 and consist of 64 channels and each channel could transmit 14 Gbps of data rate. The channels 1,6,12,18,24,30,36,42,48,54,60 and 64 were selected as samples among all channels to be investigated and analyzed. Additionally, the proposed system was investigated based on different distances and different parameters of Quality Factor (QF) and Bit Error Rate (BER). The significant contribution of the proposed system is that using the DD would result in a no-required for reference wave and that will result in a less complex system and easier to implement. Results obtained indicate higher quality QF for the sampled channel and lower BER values. For instance, the average QF obtained were in the range of 6.75-8.36 dBm and 6.77-8.35 dBm for data 1 and 2 respectively, which indicates the reliability and efficiency of the proposed system by considering all results obtained from distance variation were above the minimum threshold

Keywords: Direct Detection, DQPSK, Bit Error Rate, Quality Factor, DWDM

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1.   Introduction

The social demand for information is increasing. Internet traffic has exploded in the recent decade. This network provides the information network with basic assistance. Network traffic is increasing year after year due to high-definition digital television, online real-time streaming media, network games, interactive communications, and wireless mobile access. The thing that increased the requirement for a higher data rate of Terabit per second to support these applications. Meanwhile, reducing the implementation cost and the related complexity of the proposed schemes and systems [1-6]. Intensity modulation and simple direct detection reception mode wavelength division multiplexing are widely used in 10 Gbps systems. Larger tolerances of nonlinear requirements in long-distance vascular grids should be considered in 40 Gbps optical fiber transmission systems commercialization. Phase modulation technology is gaining popularity because of its excellent transmission and reception properties [7]. Recent research has focused on the development of a 100 Gbps optical fiber transmission system using the orthogonal phase modulation technology QPSK. In addition, it reduces chromatic and polarization mode dispersion [8, 9]. Using polarization multiplexing, a single carrier signal's capacity can be doubled, followed by polarization diversity optical coherent detection [10-12]. The most fascinating technology is Dual-Polarization Quadrate Phase Shift Keying (DP-QPSK), which transmits two QPSK signals on two polarization states of a single carrier, and is one of the 400Gbps transmission possibilities. QPSK uses four carrier phases to define digital information [13-16]. It has a smaller spectrum

breadth and a better spectral efficiency [17]. Digital coherent detection is now the standard reception method for 100Gbps DP-QPSK signals. Detection of digital coherent signals requires sophisticated hardware and algorithms [18, 19]. Coherent detection also has a residual frequency offset due to the inability to estimate the carrier frequency in non-cooperative communication contexts [20-22]. NDC, on the other hand, requires no local oscillator laser and is easy to install, making it a feasible choice for non-cooperative communication. Using DP-QPSK, several systems and approaches were presented for optimizing fiber optic communication parameters. According to [23], the authors presented a 100 Gbps DP-QPSK system employing Coherent Detection (CD) and Digital Signal Processing (DSP) to achieve a longer distance at 100 Gbps. Optisystem software was also used to investigate DC along with the proposed system. The results show a solid method for optimizing CD-based hardware. As a result, DP-QPSK modulation is a spectral efficient approach. However, the proposed system's data rate is too low to enable 5G network expansion and has to be improved. Using the CD with the suggested system would also add to its complexity.In [24, 25], authors devised a DP-DQPSK method that uses both SMF and FSO transmission mediums. The planned system covered 50.8 km and used two Erbium-Doped Fiber Amplifiers (EDFA) to compensate for transmission attenuation. The Continuous Wave laser's input power was 2dBm (CW). The system achieved 10 Gbps. Optisystem results show that using both SMF and FSO for the proposed system could increase flexibility and bandwidth efficiency. It was below the required level of 6 dBm, so it needs to be improved. In addition, [26] designed a hybrid system that used both DP-QPSK and DP-16 QAM based on fiber optic length and polarization angle. The suggested system uses DSP to deal with channel issues. The system uses an EDFA with 16 dB gain and a 50 GHz Gaussian filter. The receiver uses a CD-based approach to improve sensitivity and frequency selectivity. The results demonstrated that the BER increases with increasing polarization angle due to the transmitter's polarization mismatch. On the whole, the results were intriguing. The system did not test for more channels. Using a CD in the receiver would add to the system's cost and complexity. A DP-QPSK modulation system using the Delay Line Interferometer (DLI) was proposed in [27]. The suggested system uses Optisystem software and can carry data at 100 Gbps. The authors also offered a strategy to improve the proposed system's performance by checking the incoming data's bit stream. Even with an optimization algorithm, their results have not been widely studied and supported with values that demonstrate system reliability. Also, various impairments like CD and non-linearity effects have not been explored with system inquiry, which may be a key constraint for the suggested work's trustworthiness. Also, in [28, 29], a DP-QPSK WDM system based on FSO medium was designed. The proposed system has 32 channels, each with a data rate of 200 Gbps and a channel separation of 60 GHz. The suggested work's results were compared to other work proposed by the same authors to assess the proposed system's significance. The system achieved 6.4 Tbps across 92 kilometers in clear weather. The system uses the CD technique at the receiver, which increases system complexity and expense due to LO leakage. The proposed system has not been tested with SMF medium to examine DC and nonlinearity effects. In line with all these works, in this paper, a 64channel DP-DQPSK DWDM system would be designed and implemented with the utilization of the DD advantages, which is represented by the simplicity that enables the multidimensional modulation and guarantees the linearity between the digital compensation based fiber impairments and the optical field. Meanwhile, the advantage of using the DQPSK, sends two bits per symbol, resulting in a symbol rate half that of the bit rate and a system with less complexity. Additionally, it is immune to CD, polarization-mode dispersion (PMD), and has a high spectrum efficiency, making it suitable for ultra-long-haul transmission. The system was designed using an optic system and investigated for different distances ranged from (60-720) km. The proposed system aims to design a system toward Tbps of data rate and design a reliable system with both lower cost and less complexity. The parameters to be studied and analyzed in the system were the QF and BER.

2.   System design

The setup for the integrated DP-DQPSK DWDM system with 64 channel x 14 Gbps will be classified into three parts to be further explained, these three parts are the transmitter, medium, and receiver parts. The general view of the proposed system can be seen in Figure 1.
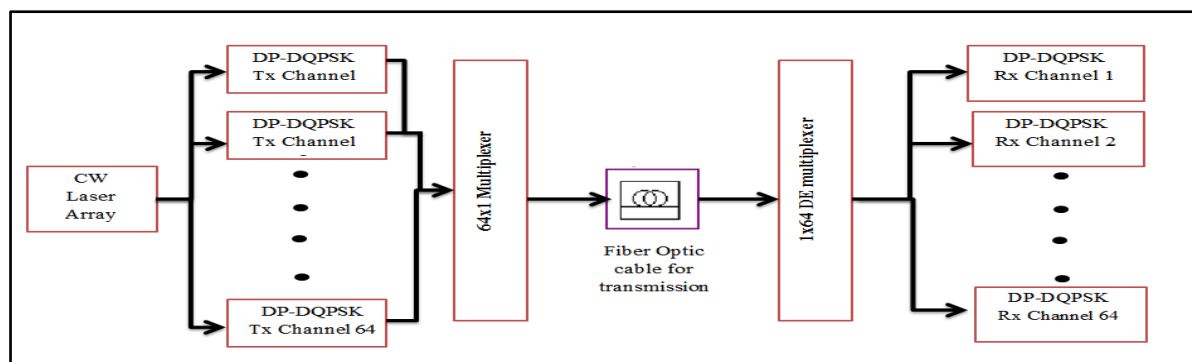
Figure 1. A general view for the proposed system

2.1. Transmitter part

The first part of our proposed system that has been implemented using Optisystem, starts with using the CW laser array element and select the number of ports to be equal to 64. Then designing the DP-DQPSK transmitter system by considering two Pseudo Random Bit Sequence (PRBS) generators with a bit rate selected of 14 Gbps. Then each PRBS would be connected to a precoder to be utilized for serial or parallel transmitter configuration. The latter would be fed to a pulse generator of type Non-Return to Zero (NRZ). It is worth to mention, that the utilized modulator was the LiNb Mack Zander Modulator (MZM). The MZ structure is made up of an input optical branch that separates entering light into two arms, then two separate optical arms that are recombined by the output optical branch. The degree of interference at the output optical branch is controlled by applying an electrical signal to one or both of the optical arms, which affects the output intensity. Then, the output of the first two MZM would be separated by using a 1x2 power splitter to be connected as an input for another four modulators of the same previously mentioned type. Finally, all output lines from the four modulators would be connected to a polarization combiner. Each line from the latter would be connected to the input port for the 64x1 multiplexer device. The parameters selected for each component within the transmitter part have been listed in Table 1. And, the transmitter design using optisystem has been clarified as seen in Figure 2 Furthermore, DQPSK is a modulation-based technique in which the carrier can take on one of four phases, each of which represents two bits. 00, 01, 11, and 10 are the bit combinations. As a result, the data stream can only transport two bits at a time. The phase transition over the origin is avoided with this strategy. The in-phase (I) and quadrature-phase (Q) data are broadcast simultaneously in a single symbol time in DQPSK. Timing alignment monitoring for the synchronization of the pulse carver and data modulator is required when a pulse carver is used to generate RZ pulses [30]. In addition, synchronization is required for the two orthogonal data channels.

Table 1. Selected parameters for the proposed DP-DQPSK DWDM transmitter part

Parameter	Value	Unit
CW laser array		
Number of output ports	64	
Line width	0.1	MHz
Initial phase	0	deg
Power	-10	dBm
Frequency	190.3-196-6	THz
Frequency spacing	0.1	THz
PRBS Generator		
Bit rate	14	Gbit/s
4-DPSK Precoder		
Transmitter configuration	Parallel	
NRZ Pulse Generator		
Rectangle shape	Exponential	

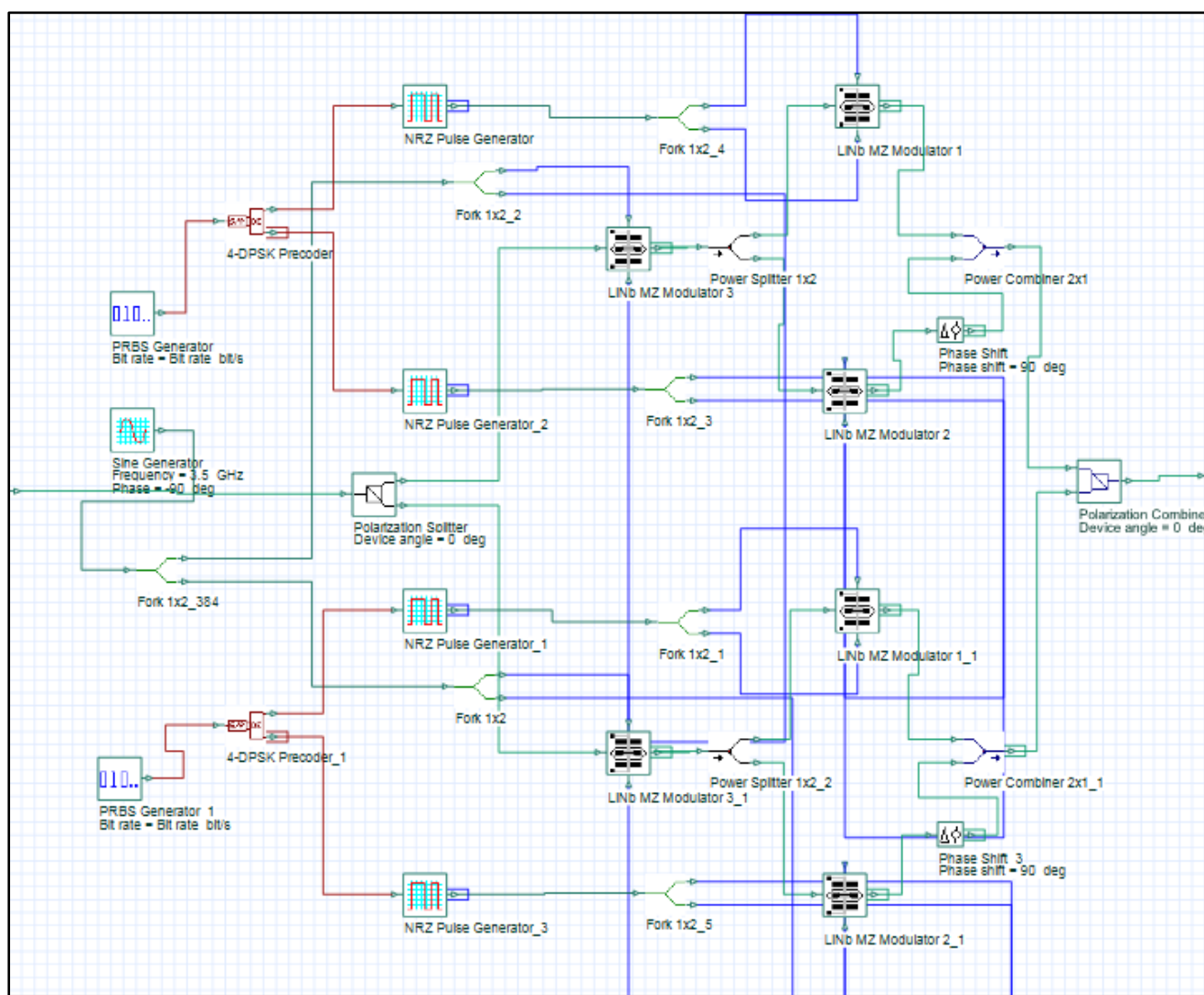| Format for pulse range	Min/Max	
LiNb MZ Modulator		
Extinction ratio	30	dB
Switching bias voltage	4	V
Switching RF voltage	4	V
Insertion loss	0	dB
Other parameters		
Phase Shift	90	deg
Ideal Multiplexer port	64	

Figure 2. The design of the proposed DP-DQPSK DWDM transmitter part

2.2. Transmission part

In this part, the optically modulated signal that out from the multiplexer line is transferred through the SMF for the selected distances of 60 x N times km (where N ranged from 1-12) through the use of loop control. The attenuation and dispersion effects are considered in the proposed design and performance analysis of our proposed systems by setting them to 0.2 dBm/Km and 16.75 ps/nm/Km. Due to the long-distance transmission, the problem of chromatic dispersion would appear. As a result, the dispersion compensation must be utilized for extending the transmission distances. Thereby, a Dispersion Compensation Fiber (DCF) has been designed for this purpose. The selected amplifier in this part was the optical amplifier to support the transmission reliability for longer distances. The design of this part can be seen in Figure 3, and the selected

parameters for the components of this part were listed in Table 2. It should be noted that the end of the proposed system would be connected to a 1x64 DE multiplexer to recombine the optical signal that has been transferred in this part.
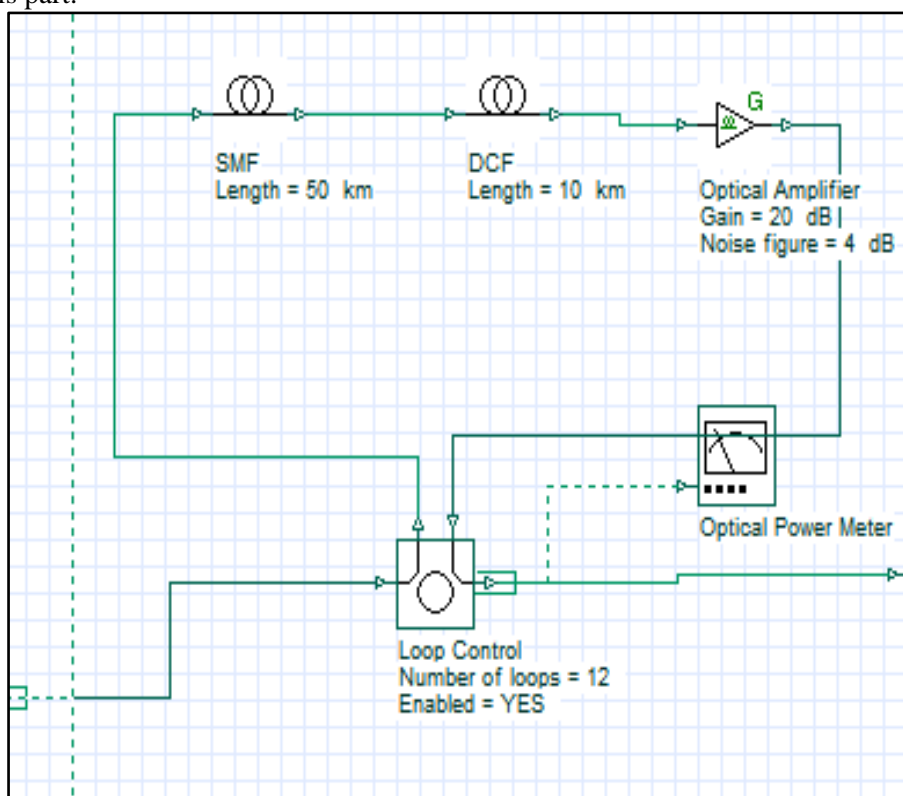

Figure 3. The design of the proposed DP-DQPSK DWDM medium part

Table 2. Simulation parameters for the proposed DP-DQPSK DWDM transmission medium part

parameters	value	Unit
SMF parameters		
Length	50	km
Attenuation	0.2	dB/km
Dispersion	17	ps/nm/km
Differential group delay	0.2	ps/km
Attenuation effect	included	
Model type	Vector	
Propagator type	Runge-Kutta 4th order	
Calculation type	No iterative	
DCF parameters		
Length	10	km
Attenuation effect	included	
Attenuation data type	Constant	
Attenuation	0.5	dB/km
Dispersion	-85	ps/nm/km
Birefringence type	Deterministic	
Differential group delay	-1	ps/km
Model type	Vector	
Propagator type	Exponential	
Calculation type	Iterative	
Optical Amplifier		

Operation mode	Gain Control	
Gain	20	dB
Power	10	dBm
Saturation power	10	dBm
Saturation port	Output	
Include noise	included	
Noise figure	4	dB

2.3. Receiver part

This part starts with the recombined 64 channel from the DE multiplexer, where each channel would be handled with an EDFA amplifier and Optical filter with a rectangle frequency transfer function. Then, the received signal would be handled with the power splitter supported by the x coupler is used to splits an optical input signal into two output signals. After that, a time delay is added to the optical signal input and add Adds a time phase to the input optical signal. Finally, the optical signal would be converted to an electrical signal by using the PIN photodetector, and data 1 and 2 of the transmitted data would be analyzed with the use of the BER analyzer tool provided by optisystem software. The entire connection for the proposed receiver part of the DP-DQPSK DWDM system can be illustrated as seen in Figure 4 and the parameters selected for this part were listed in Table 3. The advantage of utilizing the DD technique in the receiver part was the continues to dominate short-range transmissions due to its inherent advantage of simplicity. The detection without the local oscillator, in particular, not only saves the cost of one laser but also results in a colorless receiver, since there is no need to match the two lasers between transmitter and receiver. This eliminates the need for complex wavelength alignment.
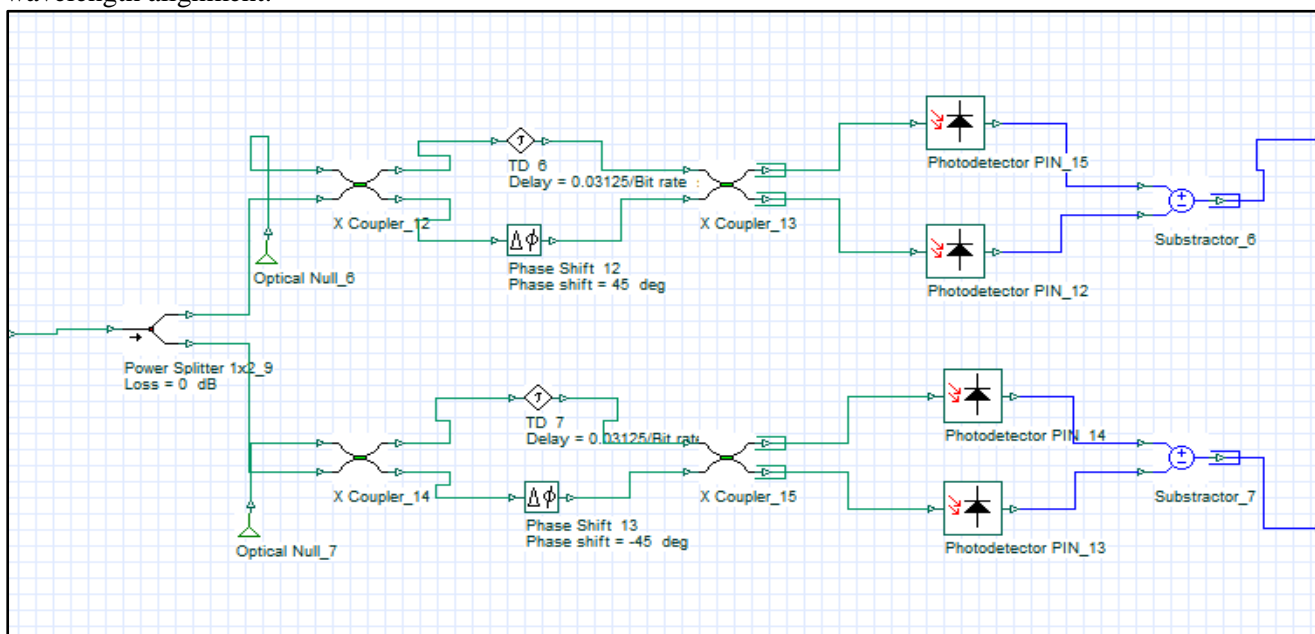

Figure 4. The design of the proposed DP-DQPSK DWDM receiver part

Table 2. Selected parameters for the proposed DP-DQPSK DWDM receiver

Parameter	Value	Unit
EDFA		
Operation mode	Gain Control	
Gain	22	dB
Power	10	dBm
Noise figure	4	dB
Rectangle Optical Filter		

Bandwidth	60	GHz
Power Splitter 1x2		
Power ratio array	1 1	
Loss	0	dB
Photodetector		
Responsively type	Constant	
Responsively	1	A/W
Dark current	10	nA
Noise calculation type	Numerical	
Noise bandwidth source	Use sample rate	
Other properties		
Delay	0.03125/Bitrate	s
Phase shift	45, -45	deg
Coupling coefficient	0.5	

3. Result and discussion

The results would be analyzed in this section and based on data 1 and data 2 obtained from each channel of the proposed DP-DQPSK DWDM system. The wavelength selected for each channel can be seen as listed in Table 3, where the wavelengths with dark highlighting represent the sampled channels that would be included with an investigation for both the parameters of QF and BER [31]. Additionally, the amount of both signal power and noise power was calculated for the proposed system and indicates significant values as listed in Table 4. As a result, to maintain the significance of the proposed work concerning power results, the SNR would be obtained based on the values of Table 4 and as shown in Figure 5.

Table 3. The utilized wavelength for each channel in our proposed system

Ch. No.	Frequency (THz)	Ch. No.	Wavelength (THz)
1	190.3	33	193.5
2	190.4	34	193.6
3	190.5	35	193.7
4	190.6	36	193.8
5	190.7	37	193.9
6	190.8	38	194
7	190.9	39	194.1
8	191	40	194.2
9	191.1	41	194.3
10	191.2	42	194.4
11	191.3	43	194.5
12	191.4	44	194.6
13	191.5	45	194.7
14	191.6	46	194.8
15	191.7	47	194.9
16	191.8	48	195
17	191.9	49	195.1
18	192	50	195.2
19	192.1	51	195.3
20	192.2	52	195.4
21	192.3	53	195.5

22	192.4	54	195.6
23	192.5	55	195.7
24	192.6	56	195.8
25	192.7	57	195.9
26	192.8	58	196
27	192.9	59	196.1
28	193	60	196.2
29	193.1	61	196.3
30	193.2	62	196.4
31	193.3	63	196.5
32	193.4	64	196.6

Table 4. The obtained signal power and noise power values in dBm for each utilized wavelength

| Frequency (THz)	Signal Power (dBm)	Noise Power (dBm)	Frequency (THz)	Signal Power (dBm)	Noise Power (dBm)
190.3	-19.953191	-63.597555	193.5	-19.953182	-63.625844
190.4	-19.952408	-63.637637	193.6	-19.952761	-63.629154
190.5	-19.952583	-63.647004	193.7	-19.952719	-63.613278
190.6	-19.952581	-63.62831	193.8	-19.952656	-63.618061
190.7	-19.952871	-63.63032	193.9	-19.952872	-63.611686
190.8	-19.95289	-63.648693	194	-19.952835	-63.611009
190.9	-19.952074	-63.640398	194.1	-19.953002	-63.617421
191	-19.952855	-63.635833	194.2	-19.953183	-63.590289
191.1	-19.952494	-63.634754	194.3	-19.953043	-63.613664
191.2	-19.952698	-63.615364	194.4	-19.952556	-63.64102
191.3	-19.952838	-63.609209	194.5	-19.952973	-63.627575
191.4	-19.952714	-63.623334	194.6	-19.953206	-63.608584
191.5	-19.952913	-63.62345	194.7	-19.952734	-63.592335
191.6	-19.952911	-63.614338	194.8	-19.952659	-63.587392
191.7	-19.952147	-63.627335	194.9	-19.953246	-63.602848
191.8	-19.953193	-63.623106	195	-19.953054	-63.621742
191.9	-19.952163	-63.635983	195.1	-19.952598	-63.630328
192	-19.9952777	-63.645858	195.2	-19.95309	-63.621781
192.1	-19.952948	-63.609393	195.3	-19.952549	-63.606351
192.2	-19.952652	-63.603575	195.4	-19.952621	-63.622723
192.3	-19.952472	-63.627461	195.5	-19.952862	-63.606149
192.4	-19.952539	-63.622726	195.6	-19.95228	-63.581239
192.5	-19.952762	-63.626934	195.7	-19.952745	-63.601026
192.6	-19.952822	-63.621836	195.8	-19.952755	-63.610408
192.7	-19.952805	-63.601075	195.9	-19.952433	-63.608503
192.8	-19.953218	-63.624722	196	-19.952757	-63.627074
192.9	-19.953031	-63.643323	196.1	-19.953035	-63.636151
193	-19.95245	-63.620638	196.2	-19.953079	-63.611266
193.1	-19.953118	-63.597022	196.3	-19.952378	-63.604585
193.2	-19.952916	-63.594158	196.4	-19.95271	-63.61775
193.3	-19.953026	-63.618781	196.5	-19.952616	-63.619143
193.4	-19.952812	-63.628447	196.6	-19.951997	-63.598336
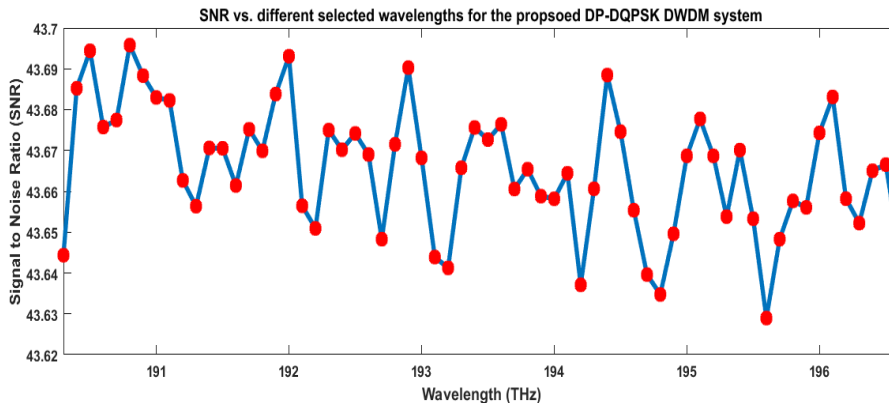
Figure 5. SNR values obtained from different wavelengths per the proposed system

The proposed system has been investigated and analyzed based on the parameters of QF and BER for concerning the variation of distances. The first investigation would handle distance start from 60 km with a fixed increment of 60 km till reach 360 km and for both data 1 and data 2 that obtained from each received channel. Meanwhile, the second investigation would handle a distance from 480 to 720 km with an increment of 120 km.

3.1. First investigation results

The first parameter to be studied is the QF as shown in Figure 6 and Figure 7 for data 1 and data 2, respectively. It can be noticed a reverse relation as raising the distance would minimize the quality of the received signal due to the increase in attenuation and cross talk effects. For the distances > 240 km, it can be seen less variation in QF values between channels due to the utilization of optical amplifier and its significance in the stability of the transmitted signal in the proposed system. Furthermore, it can be noticed that all results obtained were above the QF minimum threshold of 6 dBm.
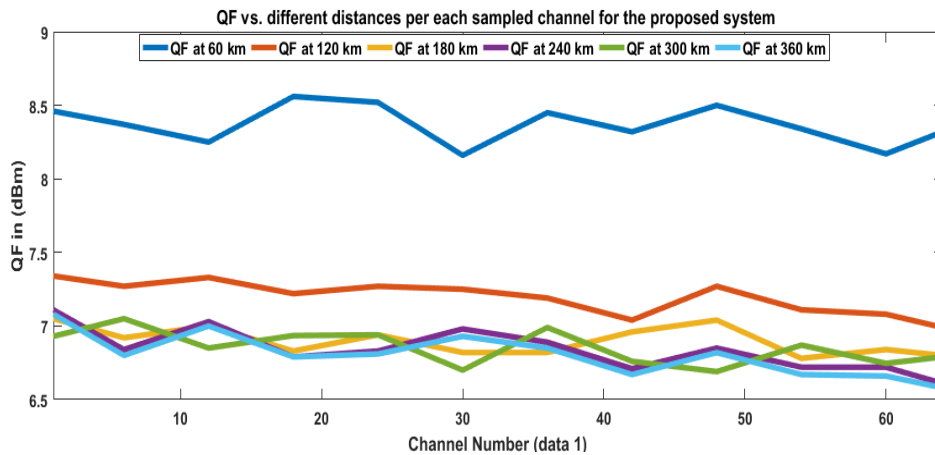
Figure 6. QF vs. different distances per each sampled channel for data 1 of the proposed system
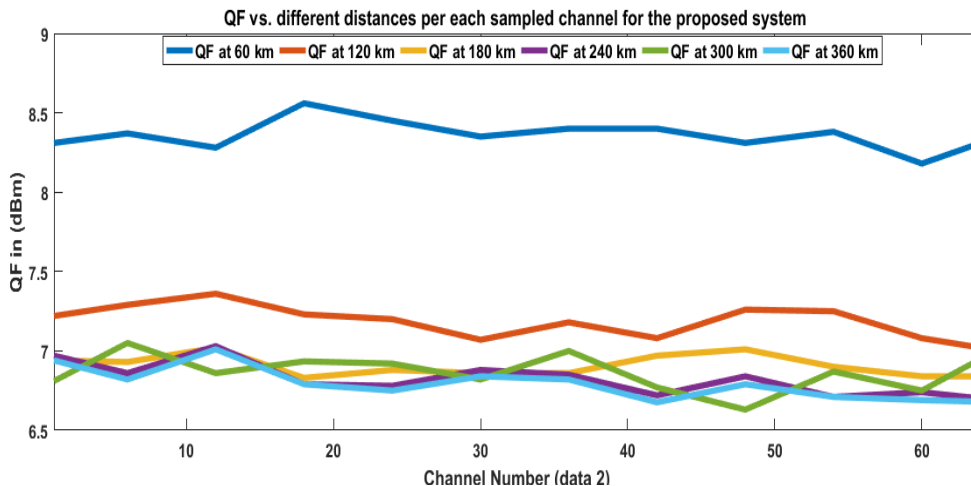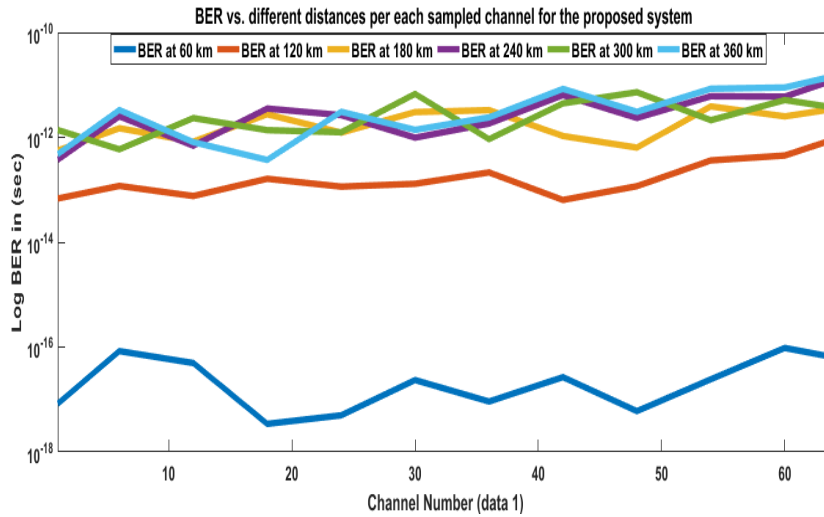
Figure 7. QF vs. different distances per each sampled channel for data 2 of the proposed system

Meanwhile, the BER parameter has been investigated for the same previous distances as seen in Figure 8 and Figure 9 for data 1 and 2 respectively. It can be found a direct relationship between distance and BER and raising the distance would increase the error in the bit received. Thereby, the effects of chromatic dispersion and interferences. In addition, for distances above 240 km, it can be seen a close curved indicating the stability of the results obtained. The variation in curves for the selected channels was due to the variation of losses per km per wavelength.

Figure 8. BER vs. different distances per each sampled channel for data 1 of the proposed system
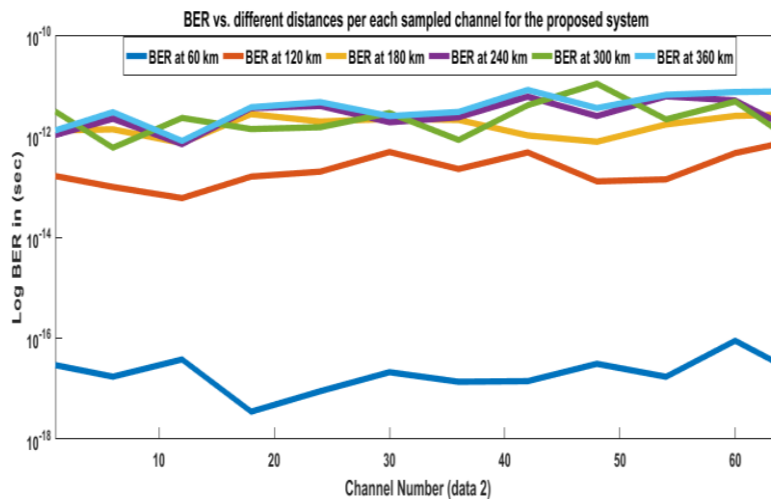

Figure 9. BER vs. different distances per each sampled channel for data 2 of the proposed system
Moreover, to get a final view about both the results obtained from data 1 and 2 it has been calculated the average QF value per distance and for the two data as seen in Figure 10 and Table 5, where can be noticed a stable and reliable quality for the received data that increase the significance of the lower cost communication system.
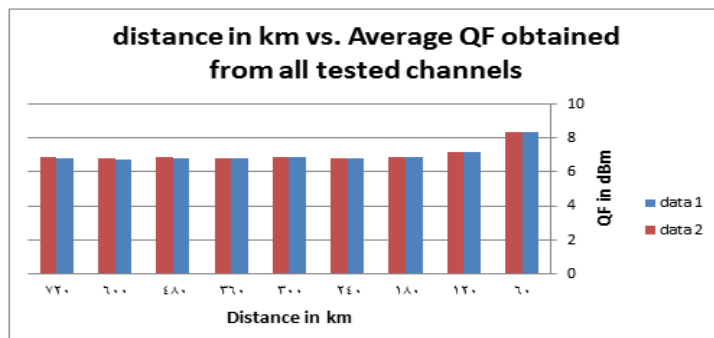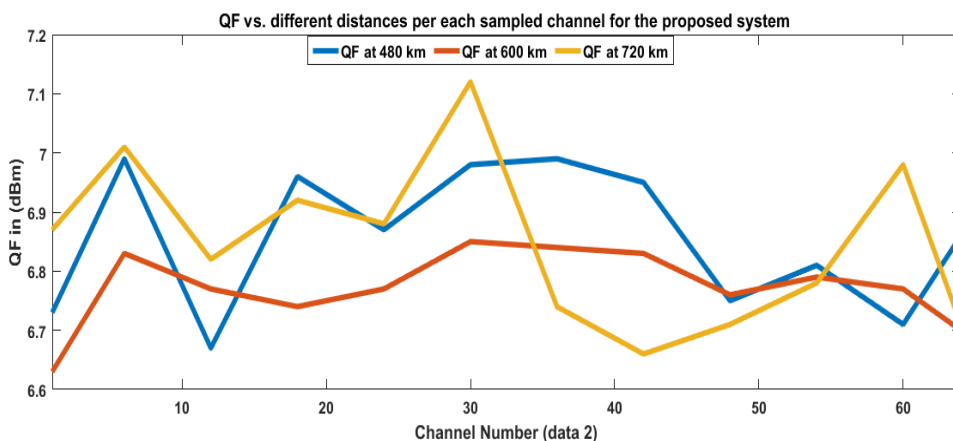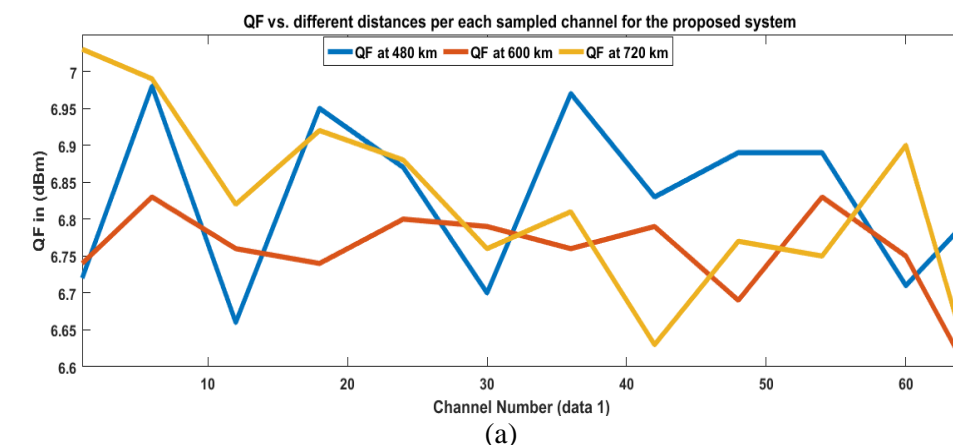
Figure 10. Average QF vs. different distances per each sampled channel for data 2 of the proposed system

Table 5. Average QF values obtained from each investigated distance

Average QF / distance	data 1 (dBm)	data 2 (dBm)
60	8.36833	8.35833
120	7.19667	7.18667
180	6.9	6.90667
240	6.84	6.8225
300	6.85425	6.86367
360	6.80492	6.793
480	6.83	6.85583
600	6.7575	6.77333
720	6.825	6.85

3.2. Second investigation results

This investigation aims to handle and test the proposed system with a higher distance (480, 600, and 720) km and based on the same parameters of QF and BER. For the QF analysis, it can be seen in Figure 11 for the two sets of data. Results obtained are not formed consistently due to reasons related to increasing the distance that raise the variation of wavelength losses. For example, channel 42 for a distance of 720 km and channel 12 for a distance of 480 km. And such a thing could be handled by setting the appropriate frequency spacing.

(a)

(b)
Figure 11. QF vs. different distances per each sampled channel for (a) data 1 and (b) data 2

For the BER parameter, it has been analyzed as clarified in Figure 12. The direct relation can't be seen properly due to reasons related to increasing distance and its impact on the BER value when the absorption would be much more than the gain. An example of that is channel 12 in case of 480 km and 42 in 720 km.
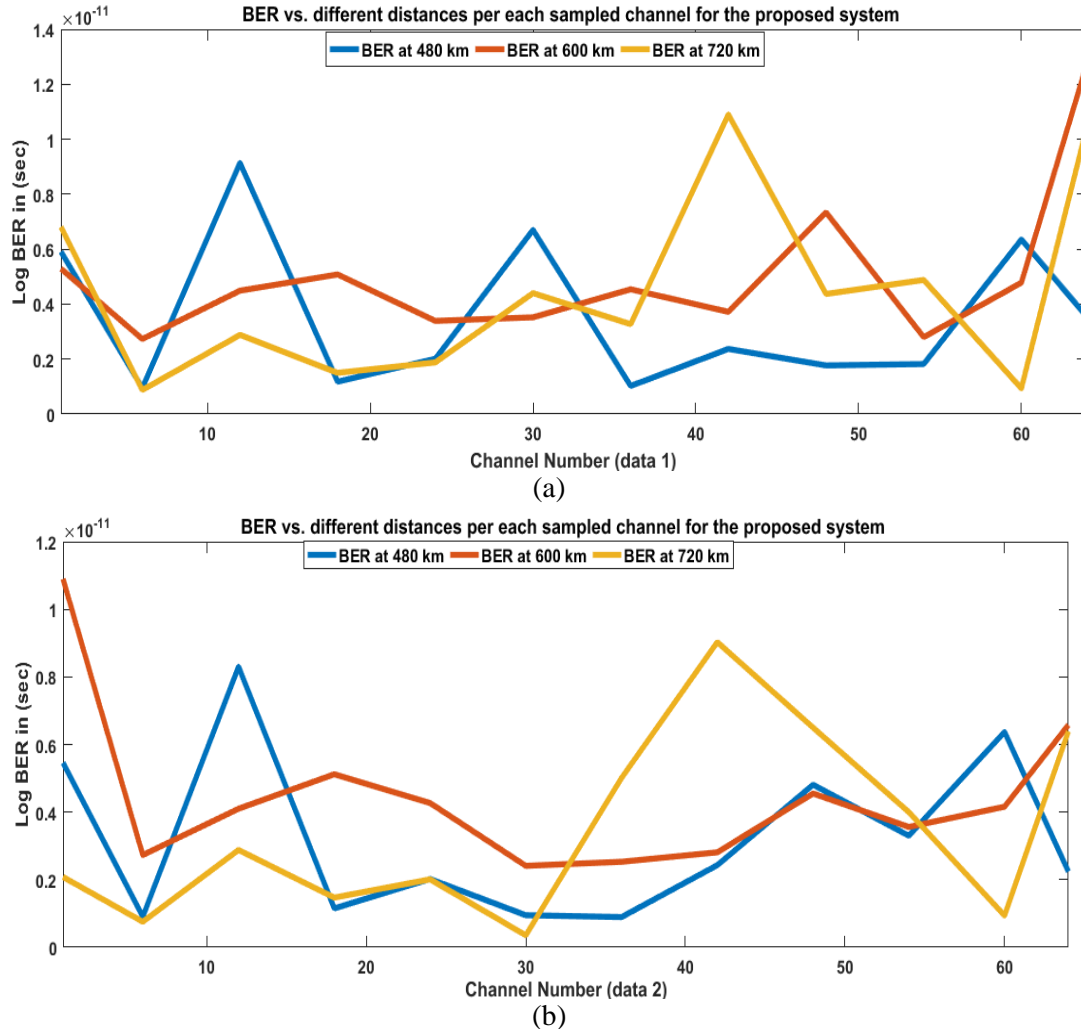

(a)

(b)
Figure 12. BER vs. different distances per each sampled channel for (a) data 1 and (b) data 2

4. Conclusion

This paper proposed a DP-DQPSK based DWDM system that supports 64 channels x 14 Gbps of data rate and with using the DD technique for handling the recovery of the optical intensity. The system was designed using an optic system and investigated for different distances ranging from 60 to 720 km. The significance of using DD for the proposed system is that it doesn't need reference waves and that will result in a less complex system and easier to implement. Analyzing results indicate higher accurate results for the studied parameter of QF and BER with reverse relation for the first and direct relation for the second and with values above the QF threshold of 6 dBm, which improve the reliability and adaptability of the proposed system in reaching a total data rate of 640 Gbps to support 5G network communication. In the future, the proposed system would be studied and analyzed with different transmission mediums.

Acknowledgment

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