Performance Analysis of Optical Communication Systems using OFDM by Employing QPSK Modulation

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Abstract: - The high data rate along with good Quality of Service (QoS) requirements of Next Generation Network (NGN) can be fulfilled by using the optical fiber communication networks. At high data rate, dispersion will be the limiting factor which needs to be suitably compensated. Many efforts have been drawn to the development of dispersion compensating devices / techniques to recover or prevent the broadening signal pulse. The Orthogonal Frequency Division Multiplexing (OFDM) is very attractive because of its capacity to handle the dispersion causing pulse broadening at the receiver without changing the internal architecture of the system. Thus Integration of Optical Communication Systems with OFDM system appears to be the most suitable technology for the NGN. The work presented here consist of the design, simulation and performance evaluation for the dispersion compensation in optical fiber communication systems using OFDM for high data rate transmission by utilizing the capacity of the optical fiber channel efficiently. The system performance has been analyzed and compared it with the single carrier optical communication systems. Various simulation results show that systems using OFDM can give dynamically tunable compensation of the dispersion by changing the various parameters of the OFDM systems. The work presented here reveals that the use of OFDM can be used to construct cost effective, high data capacity optical communication systems with extended transmission distance by employing dispersion compensation. These systems have the ability of supporting data rate up to 40 Gbps per optical channel and are appropriate for implementation as upgraded long haul high data rate optical Communication systems.

Keywords*-ofdm;dispersion;optical fiber; standard single mode fibere;coherent;dttb*

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I. INTRODUCTION

Due to the introduction of various wide band applications, such as video conferencing, broadband wireless communication etc. the demand of transmission capacity is growing exponentially. The high data rate along with good Quality of Service (QoS) requirements of the Next Generation Network (NGN) and communication systems can fulfill by using the optical fiber communication systems which works with low attenuation losses [9]. With optical fiber networks, we can achieve link capacities of the order of hundreds of Gbps but at high data rate dispersion will yield high losses which have to be suitably compensated. For a system that operates at a data rate greater than 10 Gbps, the maximum distance is on the order of few kilometers. Beyond this distance, dispersion induces signal pulse broadening that causes significant overlap of neighboring pulses and results in signal distortion. This limitation also imposes maximal distances at which electronic repeaters must be positioned along the optical link. This will increase the cost and complexity of the network.

A. Optical Communication Systems (OCS) Review

An optical communication link is a means for transmitting data from one place to another by using the light sources. A basic Optical Communication Systems is constructed from a transmitter produces the light signal, an optical fiber channel which carries the light and an optical receiver which receives the light signal transmitted for retrieving the information. The system may have additional components such as fiber amplifiers for regenerating the optical power or dispersion compensators for counteracting the effects of dispersion. The difficulties of the implementation of the optical systems vary from noncomplex (i.e., local area network) to extremely complex and costly (i.e., long haul telephone or cable TV network) [16]. The idea of using a glass fiber to transmit information light over long distances was first introduced by Kao and Hockman in 1966 [12]. This was realized when low-loss glass optical fibers were first fabricated by Coming in 1970 [13] almost at the same time, room temperature operating semiconductor diode lasers were developed by Bell Labs [14]. The combination of a compact optical transmission medium and a miniature diode laser produced a series of revolutions in fiber optical communication technology. This technology was adapted by the telecommunication industry starting in the 1970s. At present optical fiber communication systems are widely applied in different types of systems, such as long haul telephone network, Cable or Community Antenna television (CATV) networks, broadband Internet services etc., because of the ever-increasing demand for higher data rates in the transmission of multimedia services like voice, image, video, etc. The maturing of fiber optic technology and communication networks have been gradually updated with the search for more advance techniques to take full advantage of the transmission potential of a fiber link. Techniques like Dense Wavelength Division Multiplexing (DWDM), optical amplifiers, optical switchers, management of dispersion, and optical burst switching etc. enable us to load more transmission traffic on to a single glass fiber [10]. However, the pursuing for speed and bandwidth never stopped. Theoretically a single mode fiber has a potential bandwidth of nearly 50 Tbps. With optical fiber networks we can achieve link capacities of the order of thousands of Gbps [4, 32]. The Dispersion limits the maximum transmission data rate and maximal distances at which electronic repeaters must be positioned along optical link [1].

In the Single-Mode Fiber (SMF) the dominant linear impairments are Group-Velocity Dispersion (GVD) i.e., different frequencies travel at different speeds and Polarization-Mode Dispersion (PMD) i.e., different polarizations arrive at the receiver with different delays. The effect of chromatic dispersion becomes more and more critical at high data rate transmission, because the linear dispersion tolerance decreases with the square of the bit rate [15]. Fiber asymmetry (birefringence) introduces coupling between the two degenerate modes in the SMF. Furthermore, due to random nature of the fiber birefringence, the two degenerate modes arrive at the receiver with different delays [5]. Incident polarized light resolved along each optical axis experiences modified wave guiding characteristics, leading to a relative difference in propagation delay i.e., a Differentia Group Delay (DGD) between polarization modes [16-18]. The delay τ between the degenerate modes is random and is Maxwellian distributed [5] is called PMD. Though normally much smaller than GVD effects, this PMD effect can become a major link design concern in GVD compensated systems operating at data bit rates of 10 Gbps and higher [16]. The GVD is comparatively stable and linear effect, which makes dispersion compensation comparatively easy. Since the PMD is a linear affects that is time varying in fiber channels, making the dispersion compensation cumbersome [17]. Irrespective of types dispersion in optical fiber, it always degrades the performance of digital communication systems since a broaden pulse normally yields undesired Inter-Symbol Interference (ISI) and becomes the dominant limit of transmission speed and distance of optical communications and it should be small proportion of the signal bit rate. Normally, the PMD is negligible in comparison with GVD but when bit rate increases PMD becomes more and more evident.

B. *Dispersion Compensation Techniques*

A SMF has a potential bandwidth of nearly 50 Tbps; with optical fiber networks we can achieve link capacities of the order of thousands of Gbps [4, 32]. Dispersion limits the maximum transmission rate and maximal distances at which electronic repeaters must be positioned along the optical link [1]. In the SMF fiber the dominant linear impairments are GVD and PMD. The effect of chromatic dispersion becomes more and more critical at high data rate transmission because the linear dispersion tolerance decreases with the square of the bit rate [15]. As the transmission rate goes from OC-48 (2.5 Gbps) to OC-192 (l0 Gbps) or even OC-768 (40 Gbps), the dispersion compensation requirement will only become more critical for system performance. It has been observed that dispersion of a standard single mode fiber is lowest at 1300 nm, whereas it has minimum attenuation at 1550 nm. But at 1500 nm wave length the dispersion is higher. The use of dispersion shifted and dispersion flattened fibers are some of the common solutions for compensation [7]. In general, the transmission distance limited by the chromatic dispersion becomes shorter as the square of a bit rate. The problem of dispersion can be compensated by inserting an element that imposes dispersion on the optical signal that is opposite (negative) to that imposed by optical fiber [1, 21-22]. Most common is the use of Dispersion Compensation Fiber (DCF) having strong negative dispersion placed at regular intervals along the link [8]. It can actually reverse the effects of dispersion suffered by 1550 nm signals that traverse standard single-mode fiber. But it has the disadvantage of high cost, physical size, signal delay and lack of adaptability. The attenuation of the DCF requires additional optical amplifiers, which introduce additional optical noise [6, 36]. The physical characteristics of dispersion & the resulting signal distortion have been studied extensively and different techniques for the dispersion compensation have been reported. There are several different methods that can be used to compensate for dispersion, including DCF [18-21], chirped Bragg gratings [22–24], all-pass optical filters [16-19] and optical phase conjugation [19-21]. These methods restore the signal such that it can be received in a normal receiver. An alternative method is to detect the dispersed signal and perform the dispersion compensation electrically [22–24]. Using DCF a 16 channel 10Gbps DWDM system is designed for transmission over 100 Km of Negative dispersion fiber in 2001 [37-38]. Fiber Bragg Grating (FBG), which is widely used in wavelength filtering [25] and smart sensing devices [26] has become a very important technique for making tunable dispersion compensators. Ken-ichi Kitayama et al. in 2002 have investigated both theoretically and experimentally the dispersion effect of FBG used as the filter on DWDM millimeter-wave optical signal transmissions [39]. Adequate dispersion compensation is necessary to achieve error free transmission at higher data rate and low channel spacing which can be accomplished with dispersion compensation and use of FBG as filter at receiver end. Optical Phase Conjugator (OPC), Reverse Dispersion Fiber (RDF) and Negative Dispersion Fiber (NDF) are some of the other obvious solutions. However, these are not always cost effective, particularly for conventional fiber networks that are already installed. The use of repeaters and amplifiers at various points of the network to restore original signal will be more expensive for bigger networks. The use of Electronic Dispersion Compensation (EDC) i.e., digital pre-distortion will minimize the use of repeaters and the cost of building a faster network. EDC can be used to improve the data capacity of optical systems without any change in the internal or external reconstruction of the systems. This technique gives substantial saving of reinstallation cost of dispersion compensators for the system, because only end to end revulsion is needed [27]. Electronic pre-distortion [27-28] is a contemporaneous advancement of EDC, but this technique needs a backward response from receiving end to sending end [4]. The system impact of dispersion could be reduced by mean of DCFs, chirped gratings and other techniques are characterized by being static and therefore they cannot cope with any statistical or time-dependent variation. The Optical Equalizer (OE) can mitigate only one effect completely at once without being able to compensate for other impairments, but it can be expensive as compare to Electronic Equalization (EE). The electronic equalization does not represent the optimal solution for the problem we are facing with, but that on other the hand its cost can be almost negligible once it becomes commercial, since it is placed after the photodiode optical to electrical conversion where firstly, the optical channel becomes nonlinear and secondly we lose any information on the optical phase of the incoming signal. The electronic equalization is adaptable system; it does not need any previous information on the effect to deal with. It has only to be applied at the transmitter and receiver and then it can operate alone, on several impairments at once, optical and electrical. Because of the relevant advantage electronic equalizations have gained a momentum; also it presents a cost-effective solution due to its high level of integration in the receivers' electronics. Therefore we will consider only electronic equalization for compensating fiber propagation impairments; it will be the most important research area for the investigation in the near future.

C. Orthogonal Frequency Division Multiplexing (OFDM)

OFDM is a special form of multi-carrier modulation, where the individually sub-carriers are mathematically orthogonal. It is particularly suited for transmission over a dispersive channel. It deals with the problem of the dispersion in a very efficient way. One of the most significant problems in optical communication system is dispersion. The first proposal to use orthogonal frequencies for data transmission was made in 1966 by Chang at Bell Labs [31]. The next major step in the development of OFDM was made when Weinstein et al. first proposed the use of a Fast Fourier Transform (FFT) as an efficient means to generate orthogonal subcarriers in publications in 1969 and 1971 [32] making OFDM viable for electronic communications at the time. The OFDM uses IFFT and FFT algorithms for modulation and demodulation respectively. Research on OFDM has increased swiftly because it is used in different kinds of high data rate mobile wireless communications such as cellular phones, satellite communications, Digital Audio Broadcasting (DAB), Digital Video Broadcasting - Terrestrial (DVB-T) [11], the wireless networking standard such as 802.11 WLAN, and 802.16 WMAN, General Switched Telephone Network (GSTN), Digital Subscriber Lines (DSL) and Asymmetric Digital Subscriber Lines (ADSL) modems. It was not until 1990 that OFDM was incorporated into a major consumer application the wireline protocol ADSL, Cioffi et al. at Stanford University first had shown the use of Discrete Multi-Tone (DMT) basically the same as OFDM for DSL systems [33-34] which they attributed to its provision of comparatively high data rates and efficiency in terms of frequency power distribution [35]. The first application of OFDM to optical communications was shown by Pan and Green in 1996 [36].

II. DISPERSION COMPENSATION IN OPTICAL COMMUNICATION SYSTEM USING OFDM

OFDM is selected modulation technique for dispersive wireless communication channels. It allows high data rates with adequate sufficient robustness to dispersive channel losses [14]. The toughness of OFDM toward the multipath fading in the dispersive channel recommends that it may also be endurable of the consequence of dispersion in other communication channel, thus allowing the use of OFDM in previously installed optical fiber communication systems for long haul high data rate transmission. The enchantment of OFDM is principally because of it inter-symbol interference handling capacity, introduced by the frequency selective multipath fading in a wireless environment. In a single carrier communication system, a single fade or interference can cause the entire communication connection to breakdown, but in multi carrier communication systems, this will not affect adversely because there will affect only a small percentage of the subcarriers. The simultaneously parallel transmission insinuate that the input data bits are divided in to a Number of subcarriers (N) and the symbol duration is made N times smaller, which also reduces the effect of dispersion spread, relative to the symbol time, by the same factor. By using powerful forward error detecting & correcting codes along with time & frequency interleaving makes it even more robustness against frequency selective dispersive / fading environments. Multipath generates frequency selective fading and ISI, the flatness seen by a narrow-band channel overcome the frequency selective fading and modulating at a very low symbol rate, which makes the symbols excessively longer as compare to the impulse response of the channel, curtail the effect of the ISI. In OFDM communication systems the symbol period is forced to have excessive longer than the optical channel impulse response to remove the ISI effect. By embedding a guard band among the two adjacent symbols the effect of ISI is furthermore reduced. Simultaneously, a very large number of sub-carriers are utilized, to compensate loss in data rate. Ideally, an equalizer is not required at the receiving end, because there is almost no effect of ISI. In any OFDM system information about the transmission channel is ascertained by the means of a known transmitted training sequence which contains all subcarrier frequencies. The training sequence along with the Cyclic Prefix (CP), which ensures a full copy of each subcarrier is obtained by the receiver, allows channel estimation and equalization at the receiving ends because by analyzing the received training sequence the effect of dispersion introduced by the channel on any subcarrier frequency can be detected and corrected.

III. MODELING AND SIMULATION OF OPTICAL SYSTEMS

In this work, we have conducted analysis on optical communication systems with using OFDM and compared the performance with that of optical communication system without using OFDM. Here, we investigated the feasibility of transmitting 10 Gbps and beyond data rate over optical communication system with using OFDM. The performance analysis of the systems has been carried out through the various transmission parameters computation like, the Bit Error Rate (BER) / Quality (Q) Factor/ Optical Signal to Noise Ratio (OSNR) / Constellation diagram. The schematic diagram for the optical communication systems with & without using OFDM for the evaluation of the dispersion compensation capability of the OFDM is shown in Figs. 3.1 and 3.2. The same is simulated by using simulation software “Opti-System and Matlab” used by many researchers for the analysis of fiber nonlinearity and dispersion effects in optical communication systems [2-3, 40-41]. The basic key parameters of the optical communication systems are taken into consideration in the simulation; including noise and dispersion.

A. Simulation of the Optical Communication Systems using OFDM for dispersion Compensation

The Optical Communication Systems using OFDM for dispersion compensation in the high data rate long haul transmission is shown in Fig. 3.1. The various components of this systems using OFDM consist of OFDM Transmitter / Modulator, Optical Up-Converter / Transmitter, Optical Fiber Channel, Optical Down-Converter/ Receiver, & OFDM Receiver / Demodulator. The optical communication system having the data rates ranging from 10 – 40 Gbps. The fiber span ranges 0 to 200 Km. PRBS generator, generates the data stream, which is mapped by a QPSK encoder, for the QPSK modulation. These data stream is passed to 1024 sub-carriers and which is processed by the IFFT. By prefixing the CP consisting of the block of the last part of the symbol at the beginning of the symbol we can further eliminate the effect of the dispersion results in ISI.

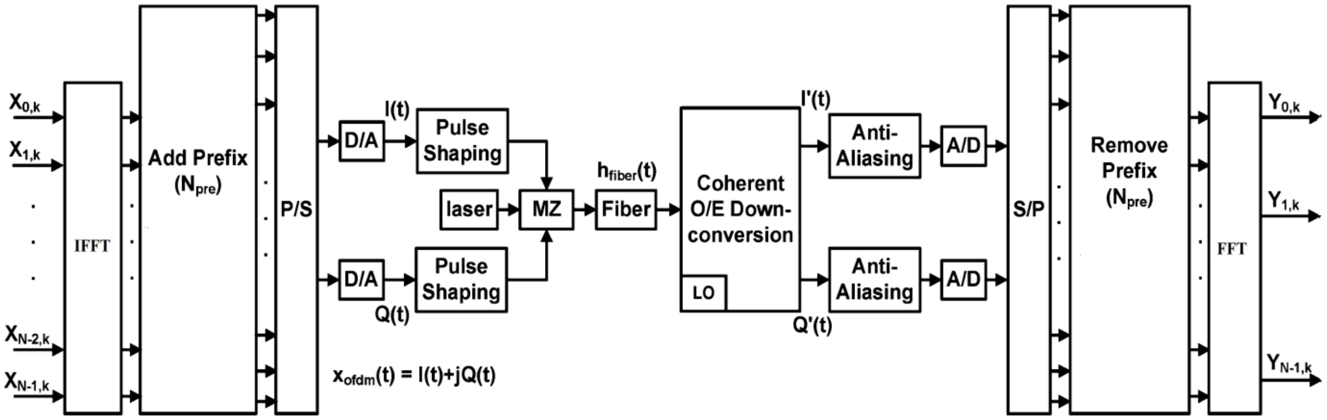


Fig. 3.1: Schematic Diagram for Optical Communication Systems using OFDM for dispersion Compensation.

The data are mapped and modulated digitally using IFFT. The MZ modulators and CW LASER used for the optical modulation. In Coherent Optical OFDM the real and imaginary components of the output OFDM signal are used to modulate both the amplitude and phase of an optical carrier. The OFDM signal consisting of in-phase part and quadrature phase part are then passing to the low pass filter. The line width of the laser fixed at 0.15MHz. The operating wavelength is 1550 nm. The various span of the optical fiber channel are of Standard Single Mode Fiber (SSMF) having the attenuation of 0.2dB/km, dispersion=17 ps/nm/km and nonlinearity coefficient = 2.09 /w/km. The OFDM modulated optical signals transmitted through the optical fiber channel and becomes distorted due to the optical fiber channel dispersion. The received signals are detected using a coherent optical receiver having a local oscillator. To reduce the noise at the receiving end an optical filter is used at the input of the receiver. The local oscillator laser is pretended to be ideally aligned and having the line width of 0.15 MHz These down convert is fed to an OFDM demodulator consisting of the FFT, followed by the decoder for retrieving the original information for the performance evaluation of the systems by measuring the various transmission parameters. The OFDM modulated signal is fed to the optical hybrid and pair of photo detector to recover the “I and Q” parts of the OFDM modulated data signal. Optical receiver noise i.e., thermal noise, shot noise, dark current and ASE noise etc. are considered. The output of the optical receiver is sent to a QPSK decoder for further processing to get the transmitted information data. The received data information along with the transmitted data are used for the computation of various performance (BER, Q-factor, OSNR and SNR for both the system and compared at the end of the receiver. The optical communication system is an ASE noise limited system. Dispersion is currently the most limiting factor in modern optical communication systems. The other effects present in the optical communication systems need not to be dealt with, since we are evaluating single optical fiber channel, and hence FWM and XPM are not generated. The focus of this work is the evaluation of the performance of the OFDM to reduce the effect of dispersion causing inter-symbol interference in optical communication systems by linear effects.

B. Simulation of the Optical Communication Systems without using OFDM

The schematic diagram for the optical communication systems without using OFDM is depicted in Fig. 3.2. The system consists of the optical transmitter, the optical fiber channel, and the optical receiver. For the performance evaluation of the optical systems without using OFDM, the various parameters, like BER, SNR, Q-factor, OSNR and constellation diagram computed and compare with the optical communication systems with using OFDM. The PRBS sequence generator output is converted into optical signals by using Mach Zehnder Modulator, which modulates optical carrier from CW laser, as a function of the externally applied voltage. Further modulated signals are fed to the optical fiber channel at the wavelength centered at 1550nm and EDFA are used to overcome the signal loss due to attenuation. The output from optical fiber consists of optical modulated signal are fed into PIN photo detector, for performing the optical to electrical conversion, followed by the Low Pass Bessel Filter (LPBF) used for the noise reduction and filtering of the electrical time domain signal.

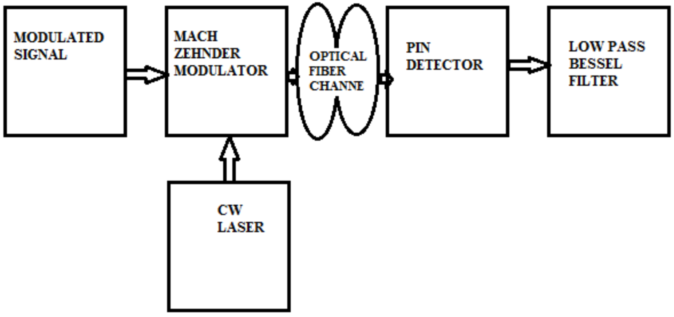


Fig. 3.2: Schematic for Optical Fiber Communication Systems without using OFDM

IV. RESULTS AND DISCUSSIONS

The optical communication system with and without OFDM configure & analyzed here for the evaluation of the dispersion compensating performance of OFDM. The performance is assessed with OFDM and without OFDM at 1.0-40 Gbps for different fiber length ranging from 0 – 170 Km. the PRBS sequence generator output data is mapped by QPSK encoders. The OFDM modulated signal is fed to the optical fiber channel model followed by the Optical receiver.

The performance of the system with and without OFDM is then assessed by evaluating the performance of the received signal. The received signal is assessed for the performance by the Signal Constellation Diagrams / BER / SNR at the receiver for different fiber spans, data rate, etc. Fig. 4.1 depicts the Constellation diagram QPSK at the transmitter end. The various received constellation diagram clearly shows that as the fiber length increases the constellation points gets distorted because the dispersion increases, which in turn reduces the overall data rate/channel capacity. Therefore we must decrease either the overall data rate or the fiber length to achieve error free uniform Distance - Data rate Product. In the following sections we have summarized various observations individually.

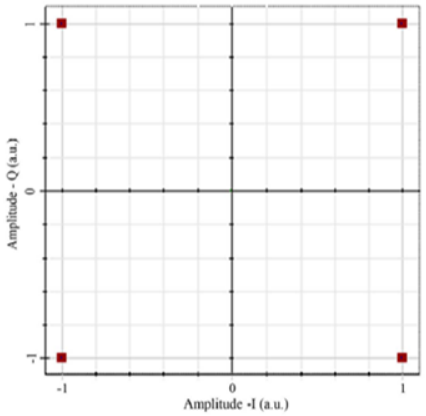
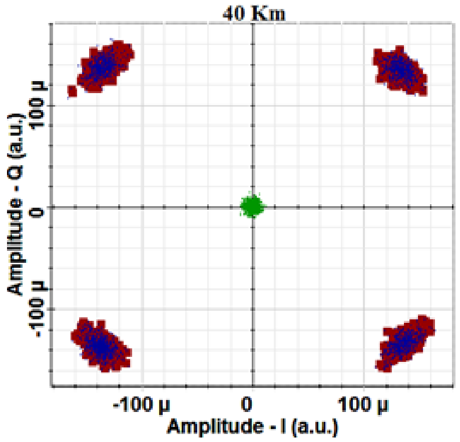


Fig. 4.1: Constellation diagram QPSK at the transmitter.

A. *Performance Analysis of Optical Communication Systems without using OFDM by Employing QPSK Modulation*

1) *QPSK 1 Gbps*

From the constellation diagram shown in Fig. 4.2 we observe that up to 50 Km the signal quality is reasonably good, after that it deteriorates due to dispersion. The BER /SNR are dependent on the length of SSMF fiber and decreases proportionately with its length as shown in Fig. 4.3, subsequently the Q factor and Bit Error Rate degrade as SSMF fiber span increases beyond 50 Km. Hence from the performance evaluation of above parameters (BER and SNR) we observe that the overall performance of the system for 1 Gbps data rate is well within acceptable / permissible level up to transmitted distance of 50 Km only, beyond that the performance is degraded.



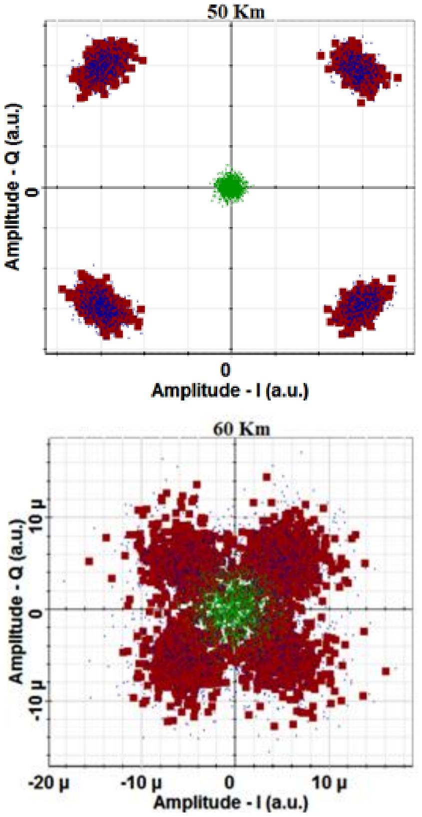


Fig. 4.2: Constellation diagram for the received data for QPSK at 1.0 Gbps data rate without OFDM for different distances (Km)

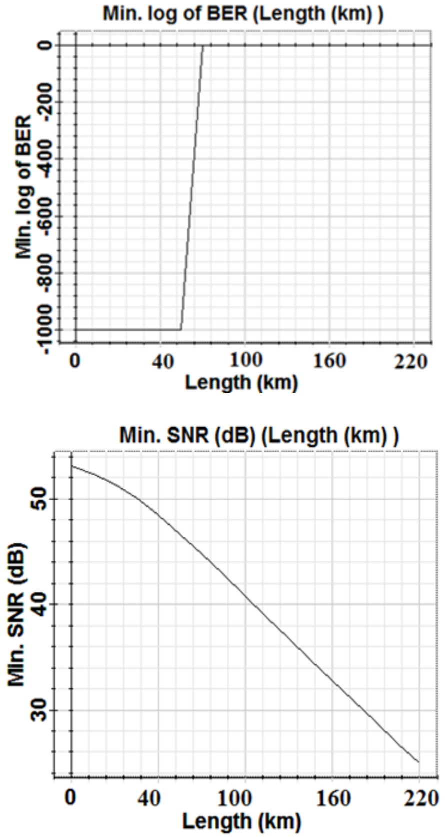


Fig. 4.3: Evaluation of various parameters (BER and SNR) v/s Length obtained without OFDM QPSK at 1.0 Gbps data rate for different distances (Km).

2) *QPSK 5 Gbps*

From the constellation diagram shown in Fig. 4.4, we observe that up to 40 Km the signal quality is reasonably good, after that it deteriorates due to dispersion. The BER / SNR are dependent on the length of SSMF fiber and decreases proportionately with its length as shown in Fig. 4.5, subsequently the Q factor and BER degrade as SSMF fiber span increases beyond 40 Km. they reduces to a negligible (distorted) value at the length of fiber around 50 Km. Hence from the performance evaluation of above parameters (BER and SNR) we infer that the overall performance of the system for 5 Gbps data rate is well within acceptable / permissible level up to transmitted distance of 40 Km only, beyond that the performance is degraded.

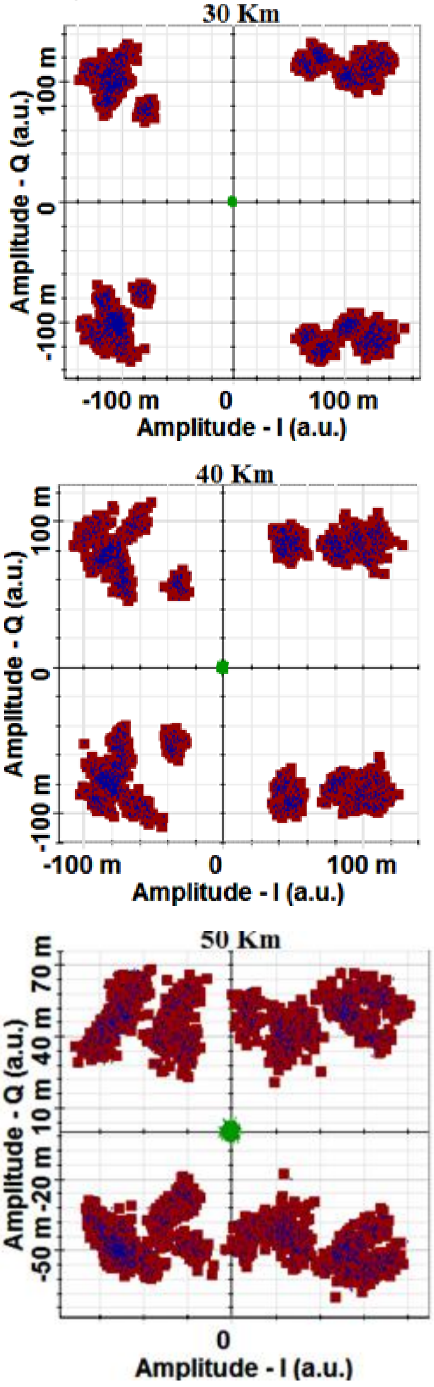


Fig. 4.4: Constellation diagram for the received data for QPSK at 5 Gbps data rate without OFDM for different distances (Km)

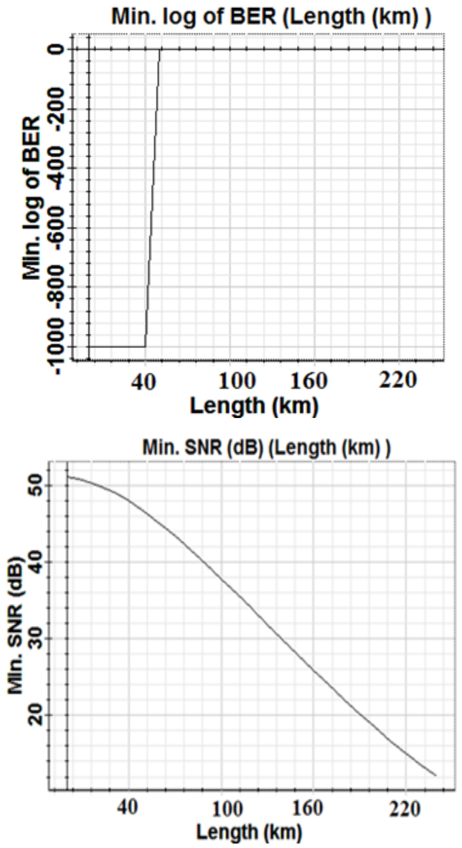


Fig. 4.5: Evaluation of various parameters (BER and SNR) v/s Length obtained without OFDM QPSK at 5.0 Gbps data rate for different distances (Km).

3) *QPSK 10 Gbps*

From the constellation diagram as shown in Fig. 4.6, we observe that up to 20 Km the signal quality is reasonably good, after that it deteriorates due to dispersion. The BER and SNR are dependent on the length of SSMF fiber and decreases proportionately with its length as depicted in Fig. 4.7, subsequently Q factor and BER degrade as SSMF span increases. It reduces to a negligible (distorted) value at the length of fiber around 30 Km. Hence from the performance evaluation of above parameters (Q-factor, BER, SNR and OSNR) we observe that the overall performance of the system for 10 Gbps data rate is well within acceptable / permissible level up to transmitted distance of 20 Km only, beyond that the performance is degraded.

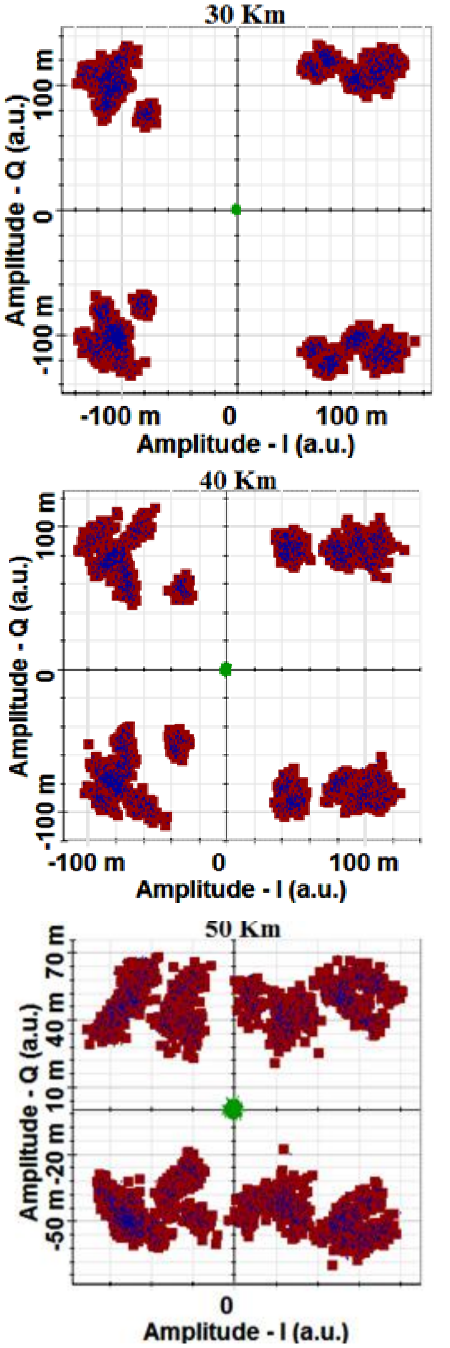
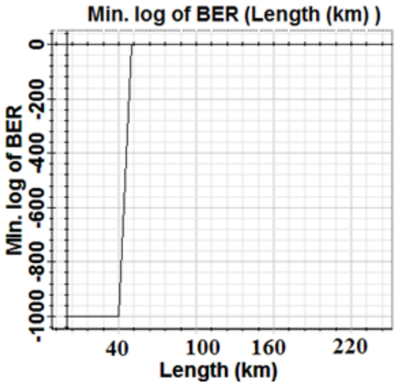


Fig. 4.6: Constellation diagram for the received data for QPSK at 7.5 Gbps data rate without OFDM for different distances (Km)



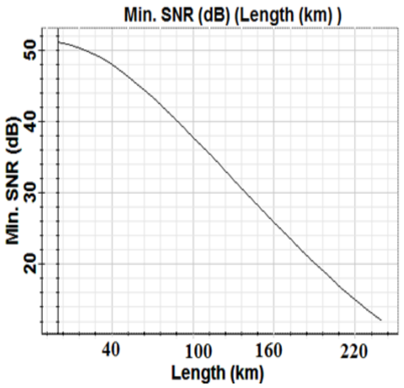
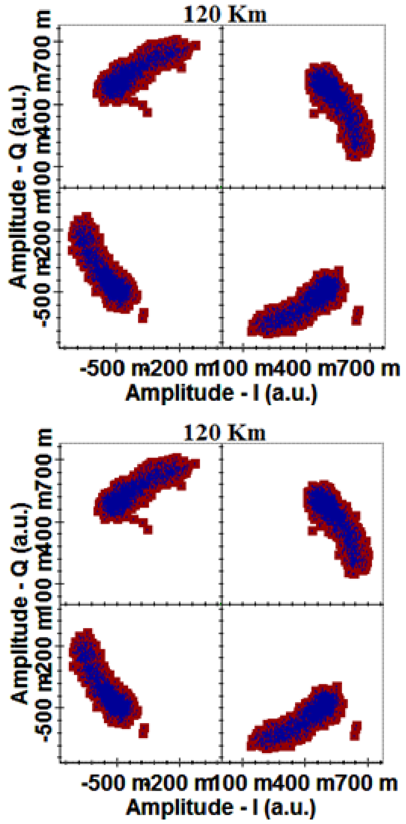


Fig. 4.7: Evaluation of various parameters (BER and SNR) v/s Length obtained without OFDM QPSK at 5.0 Gbps data rate for different distances (Km).

B. *Performance Analysis of Dispersion Compensated OFDM System using QPSK Modulation*

1) *OFDM QPSK 1024 sub-carriers 10Gbps*

From the constellation diagram as shown in Fig. 4.8, we observe that up to 150 Km the signal quality is reasonably good, after that it deteriorates due to dispersion. The BER / SNR are dependent on the length of SSMF fiber and decreases proportionately with its length as depicted in Fig. 4.9, subsequently the BER degrade as SSMF fiber span increases beyond 150 Km. it reduces to a negligible value at around 160 Km. Hence from the performance evaluation of above parameters (Q-factor, BER, SNR and OSNR) we can observe that the overall performance of the proposed OFDM system for 10 Gbps data rate with 1024 sub carriers is well within acceptable level up to transmitted distance of 150 Km only, beyond that the degradation of the performance becomes evident.



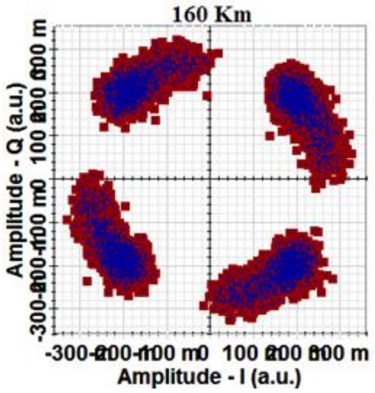


Fig. 4.8: Constellation diagram for the received data for OFDM QPSK 1024 Sub-carriers 10 Gbps data rate for different distances (Km).

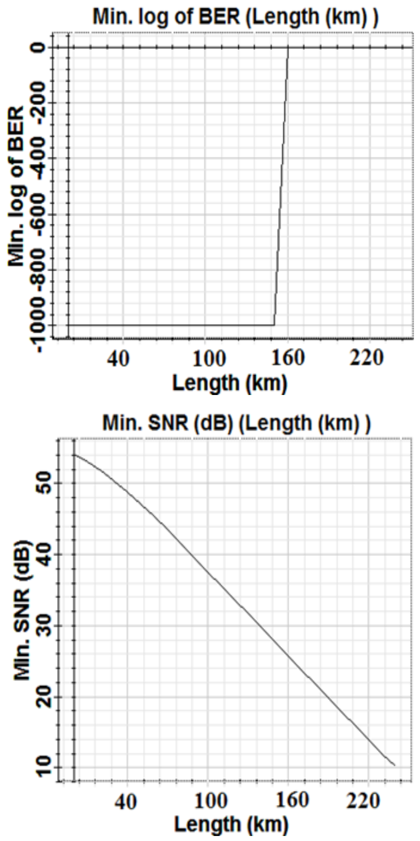


Fig. 4.9: Evaluation of various parameters (BER and SNR) v/s Length obtained for OFDM QPSK 1024 Sub-carriers at 10 Gbps data rate for different distances (Km).

2) *OFDM QPSK 1024 sub carriers 20Gbps*

From the constellation diagram as shown in Fig. 4.10, we observe that up to 60 Km the signal quality is reasonably good, after that it deteriorates due to dispersion. The BER and SNR are dependent on the length of SSMF fiber and decreases proportionately with its length as shown in Fig. 4.11, subsequently the Q factor and Bit Error Rate degrade as SSMF fiber span increases beyond 60 Km. it reduces to a negligible value at around 70 Km. Hence from the performance evaluation of above parameters (Q-factor, BER, SNR and OSNR) we can observe that the overall performance of the proposed OFDM system for 20 Gbps data rate with 1024 sub carriers is well within acceptable / permissible level up to transmitted distance of 60 Km only, beyond which the performance is deteriorated.

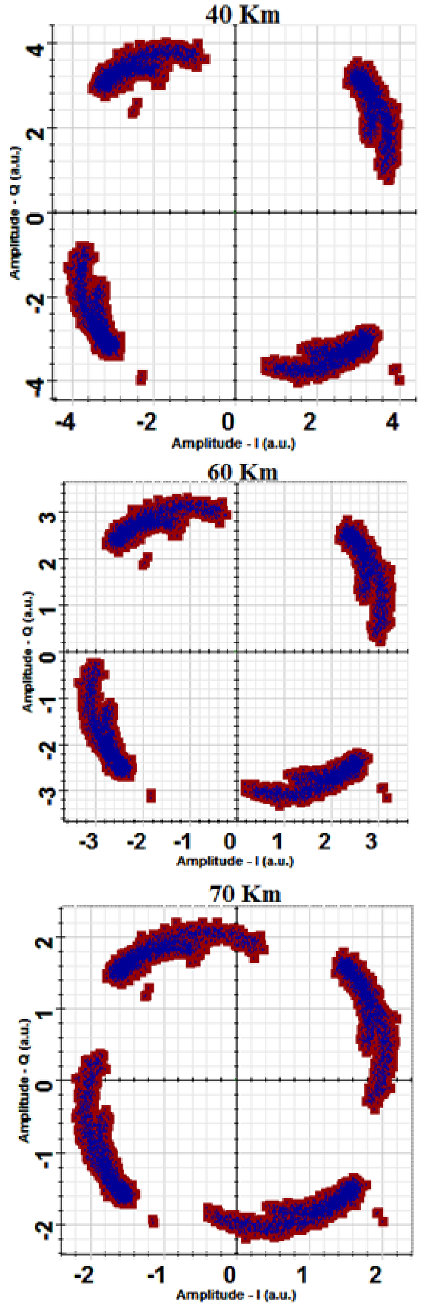
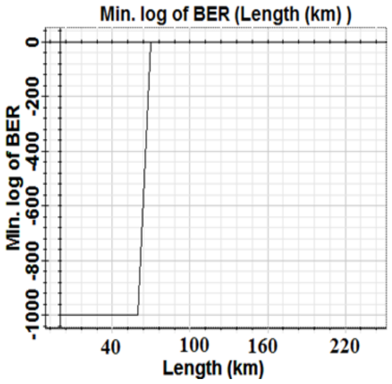


Fig. 4.10: Constellation diagram for the received data for OFDM QPSK 1024 Sub-carriers at 20 Gbps data rate for different distances (Km)



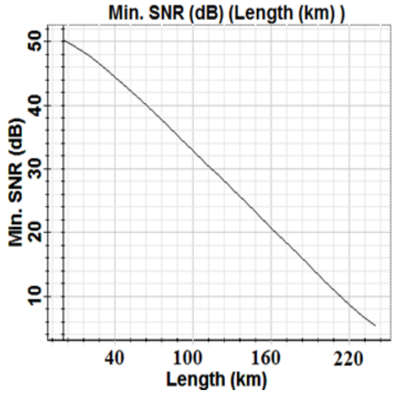
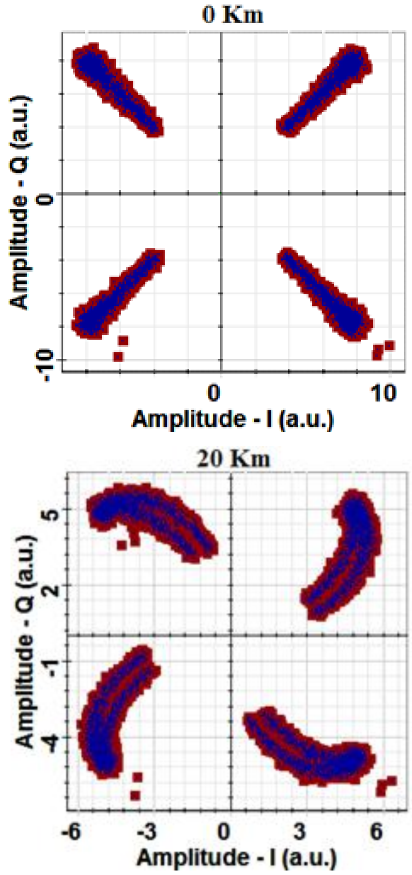


Fig. 4.11: Evaluation of various parameters (BER and SNR) v/s Length obtained for OFDM QPSK at 1024 Sub-carriers at 20 Gbps data rate for different distances (Km).

3) OFDM QPSK 1024 sub carriers 30Gbps

From the constellation diagram as shown in Fig. 4.12, we observe that up to 20 Km the signal quality is reasonably good, after that it deteriorates due to dispersion. The BER and SNR are dependent on the length of SSMF fiber and decreases proportionately with its length as shown in Fig. 4.13, subsequently the Q factor and Bit Error Rate degrade as SSMF fiber span increases beyond 20 Km. it reduces to a negligible value at around 30 Km. Hence from the performance evaluation of above parameters (Q-factor, BER, SNR and OSNR) we can observe that the overall performance of the proposed OFDM system for 30 Gbps data rate with 1024 sub carriers is well within acceptable / permissible level up to transmitted distance of 20 Km only, beyond that the performance is degraded.



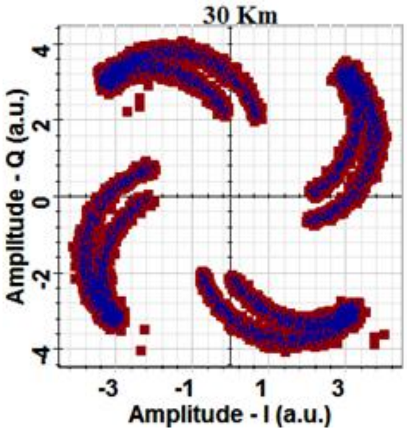


Fig. 4.12: Constellation diagram for the received data for OFDM QPSK 1024 Sub-carriers at 30 Gbps data rate for different distances (Km)

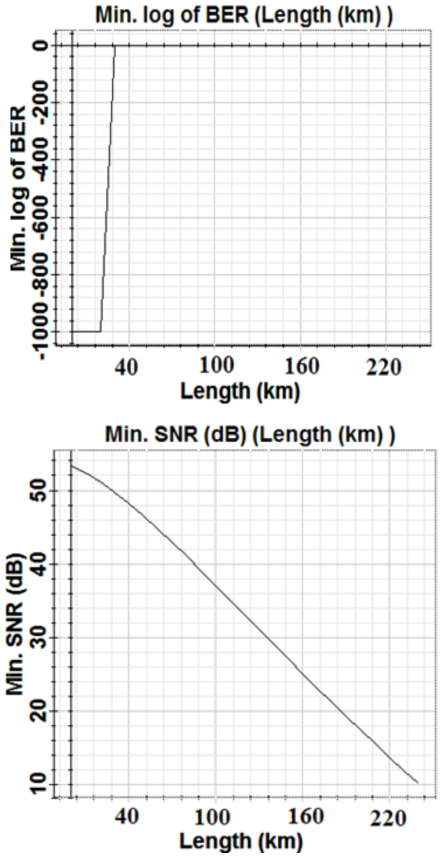


Fig. 4.13: Evaluation of various parameters (BER and SNR) v/s Length obtained for OFDM QPSK 1024 Sub-carriers at 30 Gbps data rate for different distances (Km).

4) OFDM QPSK 1024 sub carriers 40Gbps

From the constellation diagram as shown in Fig. 4.14, we observe that up to 10 Km the signal quality is reasonably good, after that it deteriorates due to dispersion. The BER and SNR are dependent on the length of SSMF fiber and decreases proportionately with its length as depicted in Fig. 4.15, subsequently the Q factor and Bit Error Rate degrade as SSMF fiber span increases beyond 10 Km. it reduces to a negligible value at around 20 Km. Hence from the performance evaluation of above parameters (Q-factor, BER, SNR and

OSNR) we can conclude that the overall performance of the proposed OFDM system for 40 Gbps data rate with 1024 sub carriers is well within permissible level up to transmitted distance of 10 Km only, beyond that the performance is highly unacceptable.

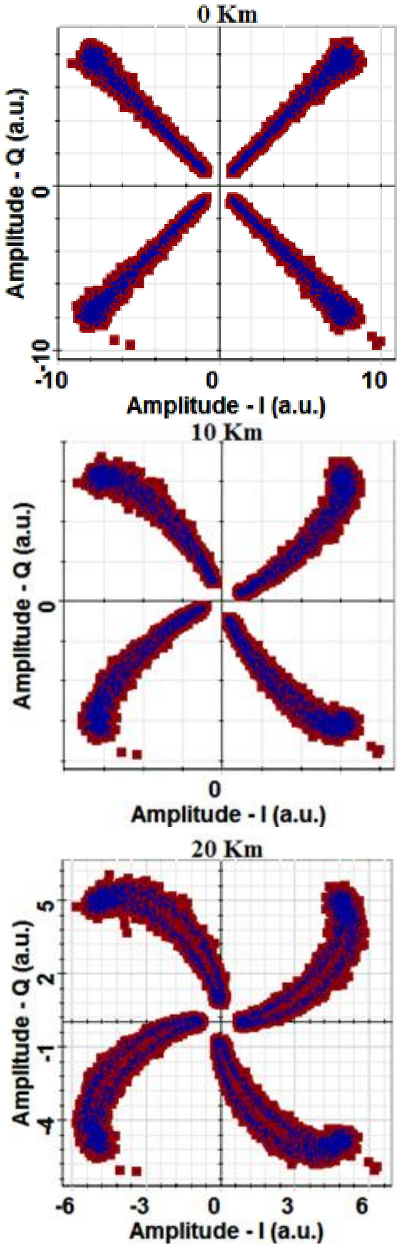


Fig. 4.14: Constellation diagram for the received data for OFDM QPSK 1024 Sub-carriers at 40 Gbps data rate for different distances (Km)

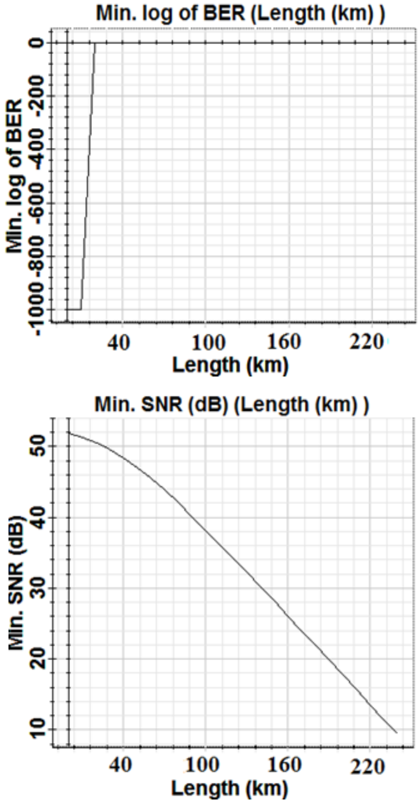


Fig. 4.15: Evaluation of various parameters (BER and SNR) v/s Length obtained for OFDM QPSK 1024 Sub-carriers at 40 Gbps data rate for different distances (Km).

V. CONCLUSIONS AND FUTURE WORK

A. Conclusion

A comparative analysis of the optical communication systems using QPSK modulation technique, without and with OFDM has been performed for combating the dispersion. The data rates varying from 1.0 - 40 Gbps at the wavelength around 1550 nm for the fiber length ranging from 10 - 200 Km, from the constellation diagrams, BER and SNR computed from the received signal, it is very much clear that as fiber length and data rate increases the received signal gets distorted due to the dispersion, results in higher bit error rate. The various symbols in the constellation gets closer and closer, results in distortion at the receiving end. Hence the performance deteriorated. Therefore we must decrease either the overall data rate or the fiber length to maintain uniform Distance-Data Rate product. The systems with OFDM give better performance in comparison with the system without OFDM. The simulated results show that without OFDM, the maximum data rate and transmission distance for the systems is much less than that with OFDM. In view of the above investigations, we can conclude that the acceptable BER performance can be achieved even up to 150 Km of the fiber length for the data rate of 10 Gbps for optical communication systems with OFDM. This shows that the optical communication systems with OFDM are one of the powerful means to mitigate dispersion, whereby it can effectively compensate the dispersion in optical communication systems without employing any separate dispersion compensating module.

B. *Future work*

According to the investigations carried out in this work, OFDM appears to be a good modulation technique for combating the dispersion for the overall dispersion compensation in optical communication systems with high spectral efficiency / high performance. In the case of OFDM, the most important disadvantages are the high PAPR and the sensitivity to phase noise and frequency offset. Some factors could not be explored here e.g., Peak to average power ratios, peak power clipping, start time error, effect of frequency stability errors etc. as the present work itself has become quite comprehensive. These factors can be studied later on along with investigations on other modulation techniques, as part of future work.

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