PERFORMANCE ANALYSIS OF 128-QAM DUAL POLARIZATION SYSTEM FOR LONG HAUL OPTICAL COMMUNICATION

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ABSTRACT

In order to deliver high data rate (content/applications) over the optical networks, higher order modulation schemes play a key role along with effective coding techniques. Quadrature Amplitude Modulation (QAM) technique is believed to be one of the vastly used modulation schemes for optical communication these days. Bandwidth utilization in higher order modulation schemes is more effective as compared to other modulation schemes. Performance of 128-QAM with dual polarization for long haul optical communication has been investigated in this paper. Investigation has been carried out at data rate of 112 Gbits/s for a fiber length of 100 Km. Simulation study enables to visualize constellation diagram, optical spectrum and optical signal in time domain. Different system impairments, such as dispersion and attenuation have also been combated by the use of Dispersion Compensation Fiber (DCF) and amplifiers.

Keywords: 128-QAM, Long haul Communication, Dual Polarization, Inter-symbol interference, Dispersion, Constellation, Quadrature Amplitude Modulation, Bandwidth, Dispersion Compensation Fiber.

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INTRODUCTION

The requirement for high data rates in optical applications has sky rocketed recently. New ways of achieving higher data rates have always been looked for, especially in optical communication (Sano *et al*., 2012). For an effective communication system, reduction of power utilization plays an important role in order to increase transmission power efficiency for which QAM is an optimum choice (Lee *et al.,* 2012). The outcomes of high speed data rate and bandwidth demand have been established after recent developments in advanced research. Due to the recent advancements in digital coherent detection technology, the practical application of more sophisticated multilevel and multidimensional modulation formats have become possible; thus making the increase happen in fiber capacity even more easier (Zhou *et al.,* 2010). Multicarrier modulation technique plays a fundamental role in achieving high data rate in broadband technology. More constellation points can be implemented by higher order modulation schemes. It is therefore possible to transmit more bits per symbol. QAM is a widely used higher order modulation scheme. Efficiency of a radio communication system can be optimized by using QAM. It relies on altering certain aspect of a carrier signal (usually a sinusoidal signal) in response to the digital signal. QAM leads PSK/QPSK modulation methods in terms of spectral efficiency. Signal recovery in QAM is also relatively easy. QAM can help reduce interference produced by a continuous carrier neighboring the modulation sidebands. Multiple sub channels can be utilized to transmit a signal over a single channel in QAM. More information bits can be carried per symbol hence increasing the data rate of a transmission link.

Digital modulation such as M-ary QAM is very much advantageous due to noise immunity and robustness to channel impairments (Haque *et al.,* 2012). QAM modulation scheme is preferable because it provides larger bandwidth and includes two dimensional multi-level coding which has advantage of larger noise margin as compared to single dimensional multi-level coding (Youssef *et al.,* 2013). Major application of QAM is found in broadband wireless LAN systems, modern terrestrial TV system and Data Over Cable Service Interface Specification (DOCSIS) modems. QAM also has its application in Worldwide Interoperability for Microwave Access (WiMAX) communication. 16-QAM and 64-QAM is used in the UK for transmitting digital terrestrial television signals with the help of Digital Video Broadcasting (DVB) (Khallaf *et al.,* 2017). 64-QAM and 256-QAM are mandated by the USA government to be used in digital cable as standardized by the Society of Cable Telecommunications Engineers (SCTE) in the standard American National Standards Institute's standard ANSI/SCTE 07 2000 (Mori *et al.*, 2009). Along with the above mentioned applications, QAM finds its uses in Global System for Mobile (GSM) /

Wideband Code Division Multiple Access (WCDMA)/ Long Term Evolution (LTE) technologies. Another advantage is that QAM coding and decoding circuits are commercially available.

Quadrature amplitude modulation has a major application in various digital radio communications and data communications. It plays a key role in better utilization of an optical spectrum for optical communication (Khallaf *et al.,* 2017). QAM is the best viable solution for spectrally efficient systems because power disadvantage can be reduced due to the increase in modulation levels (Mori *et al.,* 2009). Some common forms of QAM are 16-QAM, 32-QAM, 64-QAM, 128-QAM, and 256-QAM.

128-QAM is a type of the Quadrature Amplitude Modulation (QAM) scheme which yields 2^7 *i.e.*128 conceivable signal combinations, each symbol signifying seven bits. As a result, the transmission rate is seven times the signaling rate.

A QAM communication system can easily be represented and understood by a constellation diagram (Shashidharan *et al.,* 2015). Every possible symbol-state of a complex envelope is graphically represented in a constellation diagram. Spacing between the signals on the constellation diagram is a measure of the noise level present in the communication system. QAM constellations normally comprise of several rings (Winzer *et al.,* 2010).

QAM is also called as combined ASK and PSK. QAM modulation provides a better transmission performance because QAM constellation points are considerably more scattered in comparison to PSK constellation points. Constellation points also have large distances between them (Wang *et al.,* 2014).

In this paper, performance of 128-QAM signals transmitted through long-haul optical fiber link has been analyzed which includes repeaters, optical amplifiers and dispersion compensation fiber.

MATERIALS AND METHODS

Modeling and simulation of 128-QAM has been carried out in this research paper. Fig-1 shows block diagram of 128-QAM model. It starts with transmitter which is connected to amplifier. Amplifier combats the effects of attenuation in the system in order to provide a recoverable signal at the receiver end. After amplifier, filter is used to cancel out any un-wanted noise signals and then signal is fed into the receiver via single mode fiber. It is important to keep in mind that standard single-mode fiber has a chromatic dispersion of 16 ps/ (nm·Km) and polarization-mode fiber has dispersion of 0.2 ps/nm. Km with loss of 0.2 dB/Km (Jiang *et al.,* 2015). The non-linear effect known as Kerr effect restricts the capacity in optical fiber cables, reducing the maximum attainable rate when the input power is increased (Essiambre *et al.,* 2010).

From receiver, the signal goes into universal DSP where signal processing is done and afterwards it goes into the decision polarization. After decision polarization, QAM modulation is applied on the signal which is fed back to the transmitter. The 128-QAM transmitter is shown in fig-2.

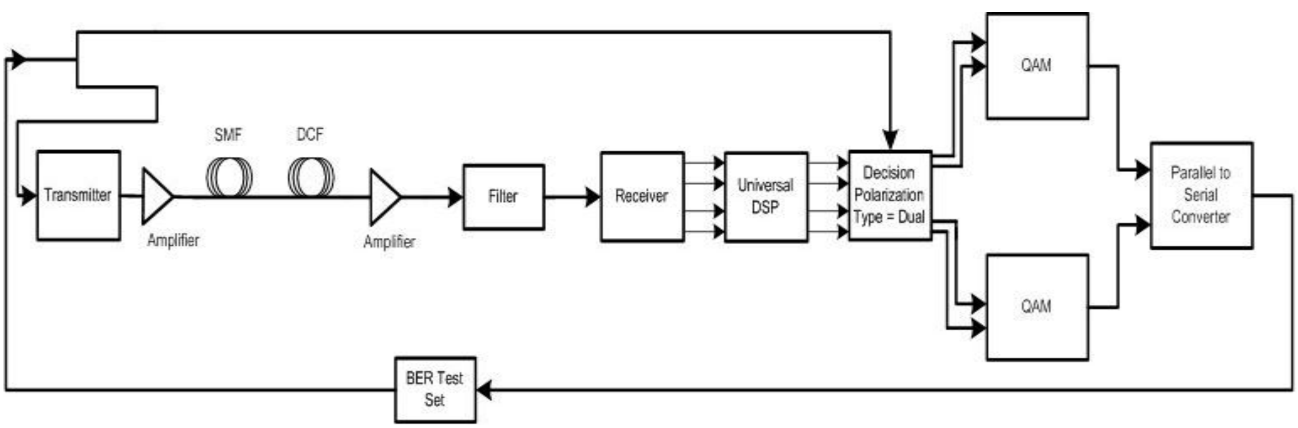

Figure-1: **Block diagram of 112-Gbit/s Dual Polarization 128-QAM Communication Model**

128-QAM Transmitter: The transmitter comprises of QAM sequence generator, M-ary pulse generator, CW Laser, Polarization splitter, LiNb Mach-Zehnder modulator and polarization combiner. The transmitter applies the discretionary pulse shaping and up-conversion on the QAM symbols converted from the bits via transmitter. In order to easily understand complex modulation schemes as QAM, constellation diagram is a useful tool. It helps in studying the real and the imaginary (in-phase and quadrature) components of the complex signal. Another important consideration to keep in mind while designing a system is pulse shaping. Pulse shaping has to be done carefully as a wide pulse will overlap the adjacent pulses causing Inter-Symbol Interference; (ISI).

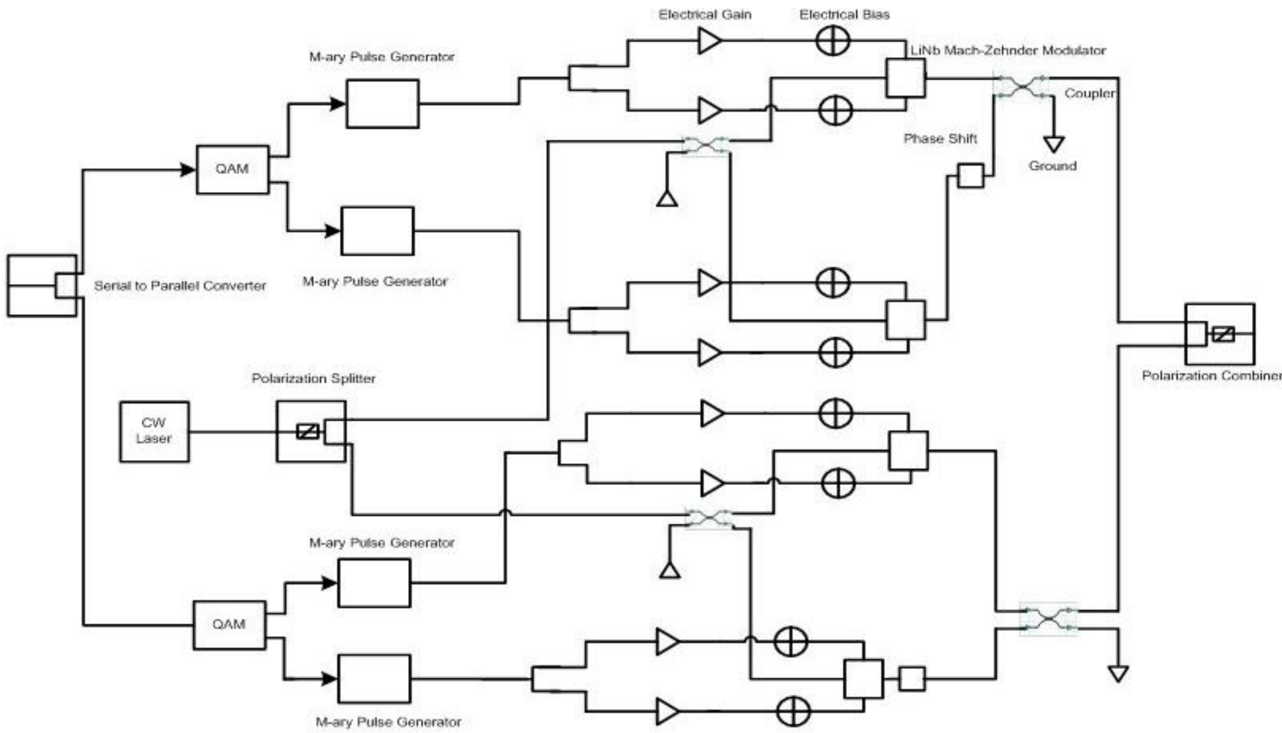

Figure-2: Schematic diagram of 128-QAM Transmitter

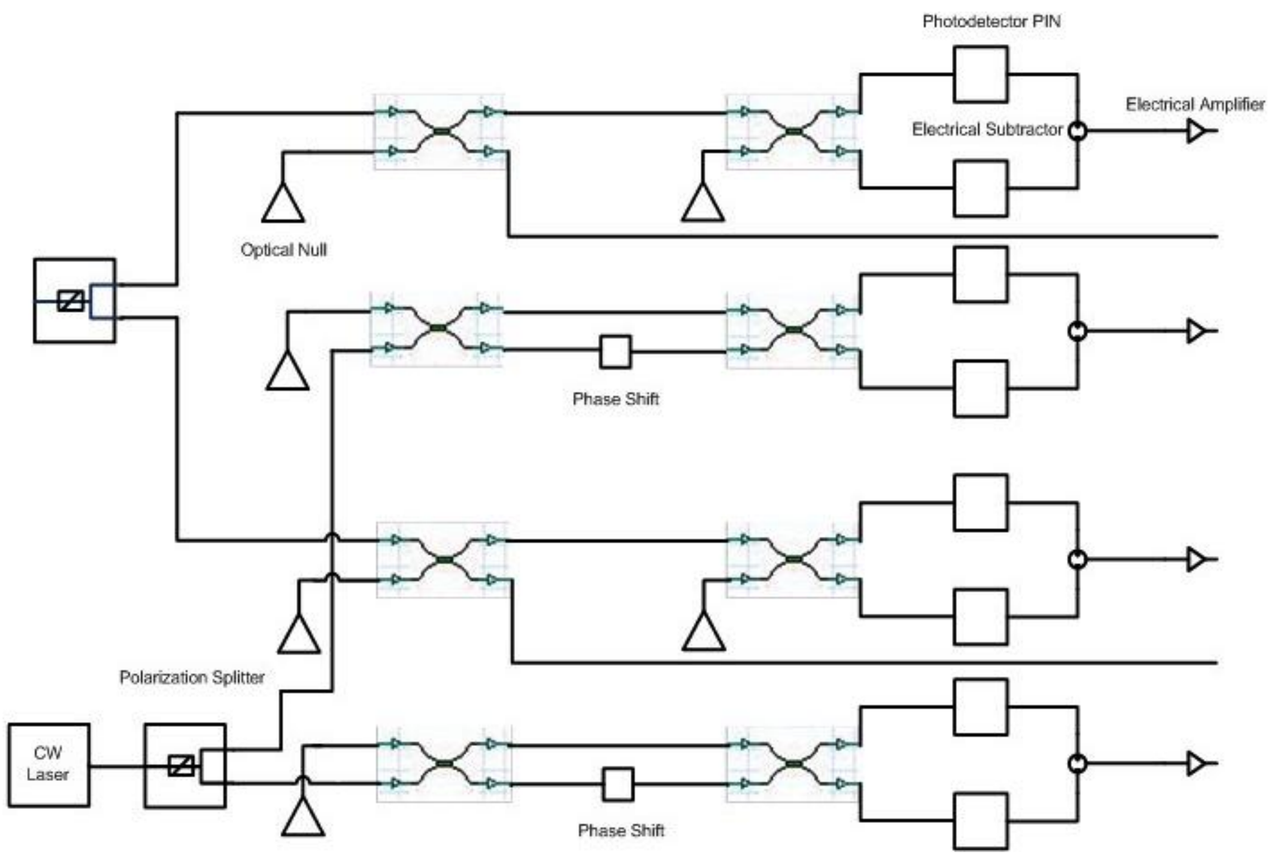

Figure-3: Schematic diagram of 128-QAM Receiver

In the transmitter circuit, a serial to parallel converter is coupled to a QAM sequence generator. QAM sequence generator feeds the input into the M-ary pulse generator, which transforms the QAM signal into pulses. Electrical gain is applied to QAM signal which later, enters in LiNb Mach-Zehnder modulator. LiNb Mach-Zehnder modulator combines the electrical QAM signal with the optical signal from CW laser.

128-QAM Receiver: Receiver block comprises of Polarization Splitter, optical null, phase shifter, photodetector, electrical subtractor and amplifier. Receiver is shown in fig-3. The receiver is one of the most complex part in the system. It reverses the function performed by the transmitter. There are many factors which can distort the original signal at the receiver. The main deteriorating factors are noise added by the environment, diffraction, scattering and multipath effects of reflection. Therefore the simulated and actual results can never be the same unless these factors are accounted for (Riche *et. al.,* 2012).

Important Parameters: The proposed communication model has a data rate of 112 Gbits/s. Using high data rate is a difficult task, because higher data rate has challenges like noise and attenuation. In order to cope with these issues, optical amplifiers are used before and after the optical fiber cable. Gain of the amplifiers is set at 20 dB. In the global parameters the sequence length is 65536 bits. 4 samples per bit are used and total number of samples is 262144. Total number of guard bits is 10. Gaussian Optical Filter is used for filtering purpose with frequency corresponding to 1550 nm wavelength and bandwidth of 35 GHz. DSP block is used for signal processing. Main DSP properties are the polarization and modulation types. Polarization type is dual and modulation type is set as 128-QAM. As the signal is QAM; the constellation type is set as square. Then decision circuit is implemented. The decision circuit will measure a probable value of signal and make an output signal decision depending on the value of input signal and predetermined criteria.

Mathematical Model: QAM includes both amplitude and phase modulation. General form of M-ary QAM signals is defined as:

$$s_{(i)}t = \sqrt{\frac{2E_{min}}{T_s}}\, a_i \cos(2\pi f_c t) + \sqrt{\frac{2E_{min}}{T_s}}\, b_i \cos(2\pi f_c t),$$
$$0 \le t \le T, i = 1,2, \ldots\ldots \mathrm{M}$$

(Surekha *et al.*, 2011);

For M > 4, minimum Euclidean distance of M-QAM signal is greater than MPSK, MASK and other multi-ary modulated signal. When M is between 2 and 4, Euclidean distance is equal to the Euclidean distance of MPSK signals. Mathematically, M-QAM signal can be expressed by the following equation:

$$s_{mn}(t) = A_m \cos(2\pi f_c + \theta_n)$$
$$m = 1,2, \ldots, M_1 \;\&\; n = 1,2, \ldots, M_2$$

The combined amplitude and phase modulation results in the simultaneous transmission of $\log_2(M_1.M_2)$ bits/symbol.

In an M-QAM system,

i) Constellation points will become more and more intensive as the value of M is increased. The reduced distances between the vector points are prone to error, causing code cross-talk.

ii) Normally, the original data is binary. Binary signals are first converted into M-ary signals along with quadrature modulation then they are added to achieve desired M-ary QAM signal.

There are many advantages of QAM modulation technique over the other modulation techniques. It has better noise resistance and is more adaptive towards channel change. It is also more effective in bandwidth utilization.

RESULTS AND DISCUSSION

QAM impairment compensation for Long Term Evolution (LTE) transmitter using Artificial Neural Networks has been discussed in (Anastasijevic, *et al.*, 2015). The Bit Error Rate (BER) can be reduced by increasing the Signal-to-Noise (S/N) ratio (Andrew *et al.*, 1989). MATLAB simulation model can be used to evaluate for adaptive QAM scheme (Xiaolong, 2008).

Optical spectrum, optical time domain signal and constellation diagram of the 128-QAM system are investigated in this section. This long haul system has a fiber link of 100 Km. Different system impairments show their effect on the transmitted signal which are mitigated by applying different measures. Interference of adjacent bits increases with increased order of QAM (Nikolaos, 2017). Signals are compared before transmission and after reception in order to demonstrate the minimization of the unwanted effects on the signal. Mean Square Error Analysis has been carried out as an effective measure of QAM performance (Savaux, 2015). Effect of misalignment on spectral density has been discussed by **(**Faulkner, 1992). Experimental demonstration of 2.56 Tb/s based on polarization division multiplexing has shown spectral efficiency of 5.1 b/s/Hz (Tian *et al*., 2013).

Keeping above impairments and their impact on the performance of 128-QAM transmission following parameters of some important components have been selected for analysis. The analysis scheme is such that arbitrary parameters can be entered in the program. Parameter selection in the following table is arbitrary with practical application of the system and availability of the respective components. Abbreviations used in the table are SMF Single Mode Fiber, CW Continuous Wave and DSP Digital Signal Processing.

Using the above parameters in the simulation optical spectrum, optical signal in time domain and constellation diagrams have been observed as below.

At a data rate of 112 Gbits/s following is the optical spectrum at transmitter end before the signal enters the optical fiber (fig-4). Plot has been drawn between signal strength in dBm versus wavelength in meters.

Table-1: Important System Parameters.

Component	Parameter
Optical Fiber (SMF)	Length = 100 Km
Dispersion Compensation Fiber (DCF)	Length = 20 Km
CW Laser	(Power) = 10 dBm
CW Laser	(Wavelength) = 1550 nm
Amplifier	Gain = 20 dB
Gaussian Optical Filter	Bandwidth = 35 GHz
Universal DSP (Modulation Type)	Dual 128-QAM
Universal DSP (Polarization Type)	Dual

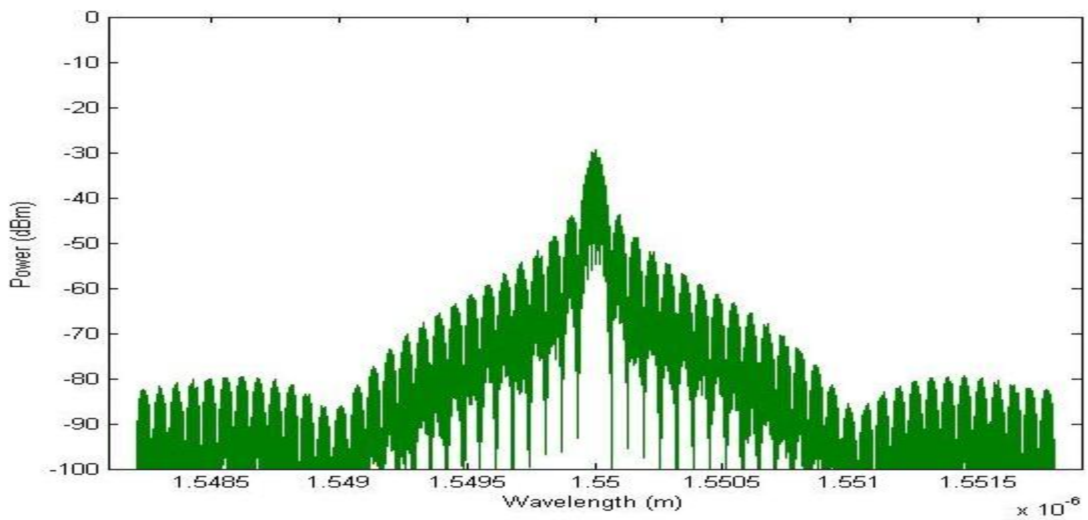

Figure-4: **Optical Spectrum before the signal enters the fiber**

Signal deteriorates while passing through the optical fiber. The optical spectrum at the terminating end of the fiber as depicted in fig-5.

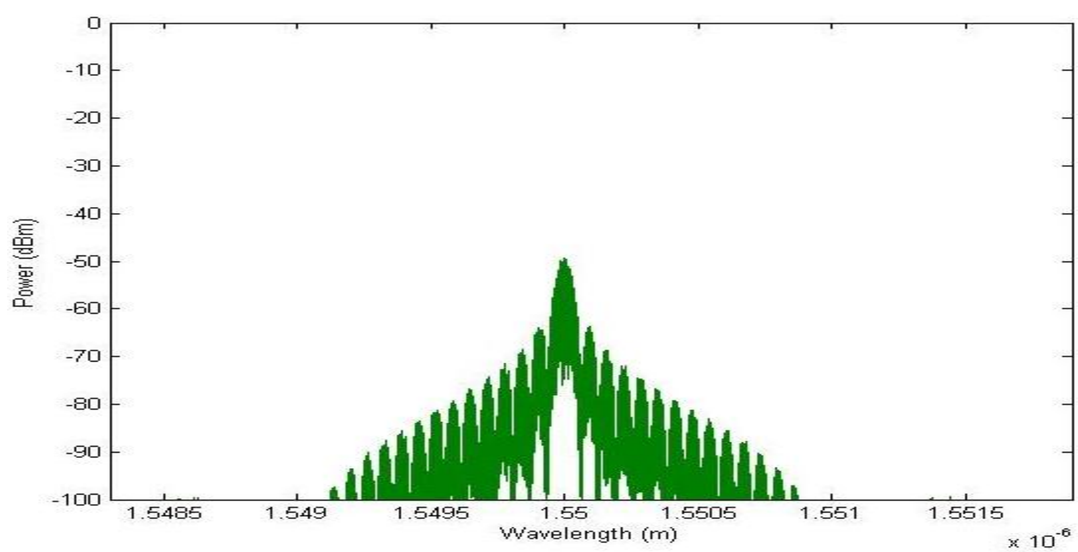

Figure-5: **Optical Spectrum after the signal passes through the fiber**

In order to recover the original signal, optical amplifier having a gain of 20 dB is used which helps in restoring the original signal. Optical spectrum after amplification is shown in fig-6. Axes are the same in all three graphs as explained in fig-4.

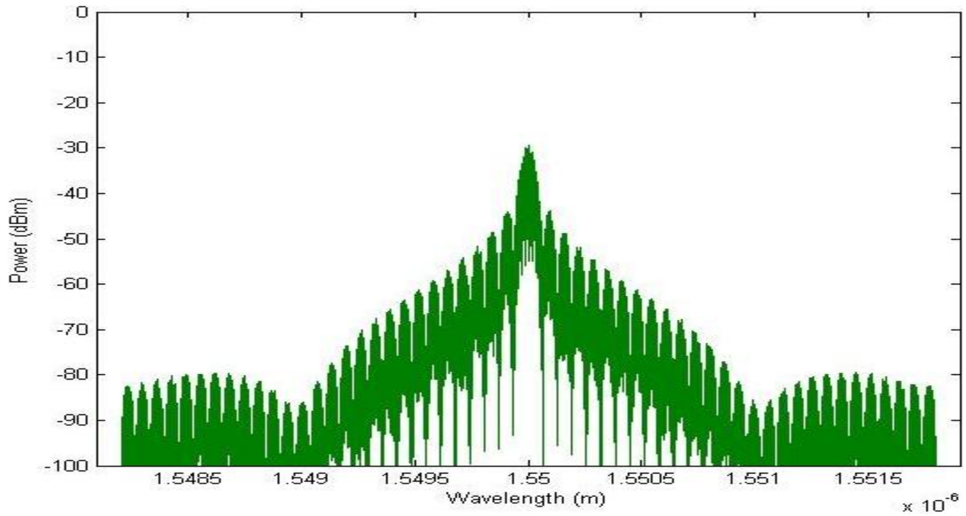

Figure-6: **Optical Spectrum after amplification**

Optical signal strength in time domain over a specified interval of time is also measured. Time domain signal before entering the optical fiber is drawn in fig-7. Vertical axis show signal power in dBm and horizontal axis is time in seconds.

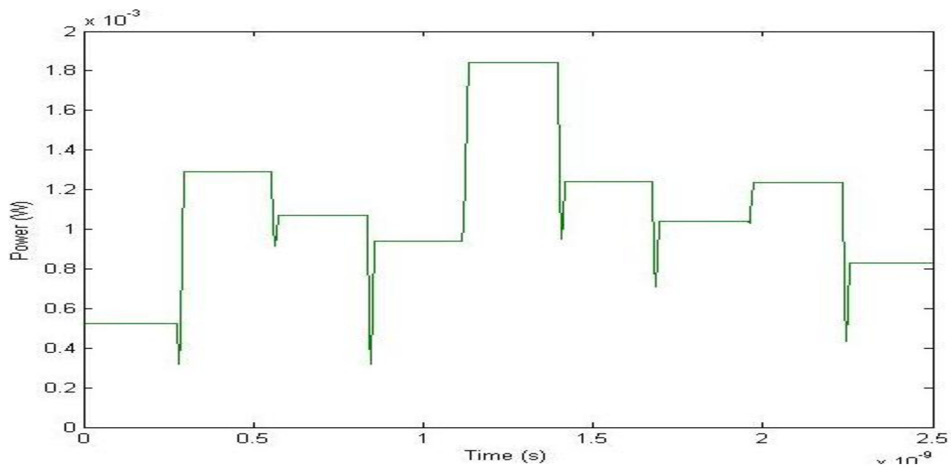

Figure-7: **Optical Signal in time domain before the signal enters the fiber**

After passing through the fiber the signal becomes distorted due to the system impairments. Distorted time domain signal after passing through the optical fiber is shown in fig-8.

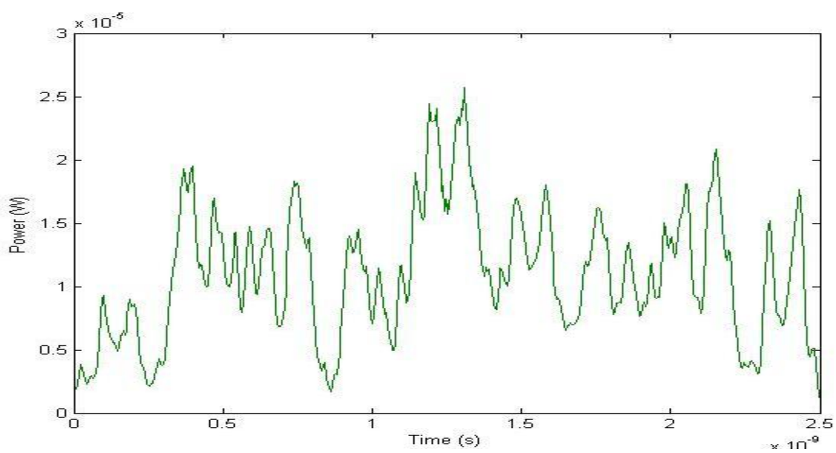

Figure-8: **Distorted Optical Signal in time domain after passing through the fiber**

In order to tackle this distortion, DCF (Dispersion Compensation Fiber) is introduced in the system along with amplifier. Signal recovered after DCF and amplifier is shown in fig-9.

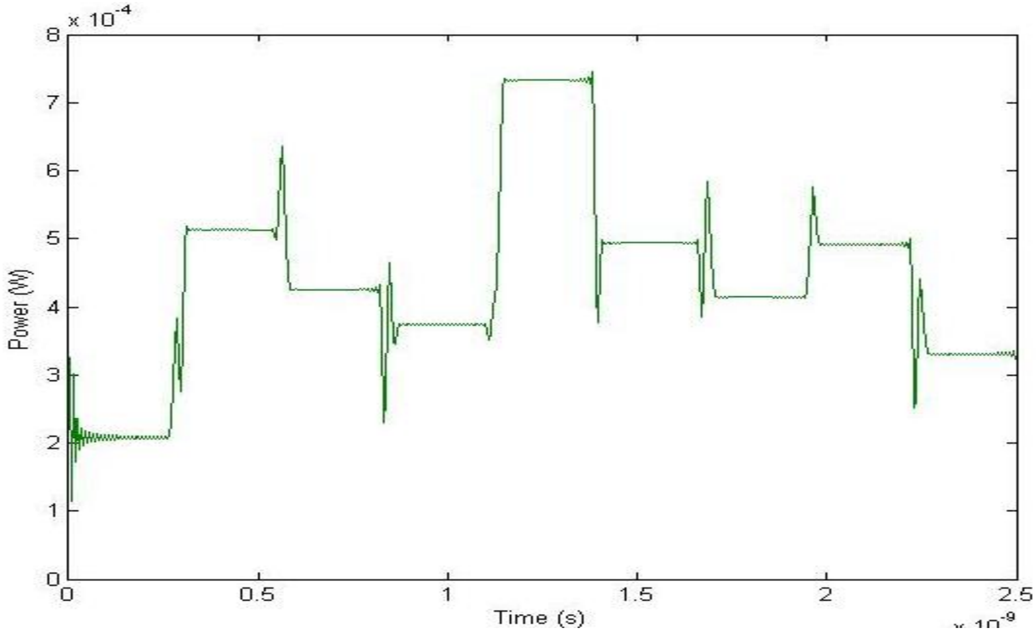

Figure-9: **Recovered Optical Signal in time domain after using DCF**

Constellation diagram for 100 Km length shown in fig-10 at the receiver end is almost identical to the signal at transmitter end. Optical fiber cable used has a loss of 0.2dB/Km and in order to neutralize this loss, optical amplifier having a gain of 20 dB is used. This amplification results in a clear constellation diagram.

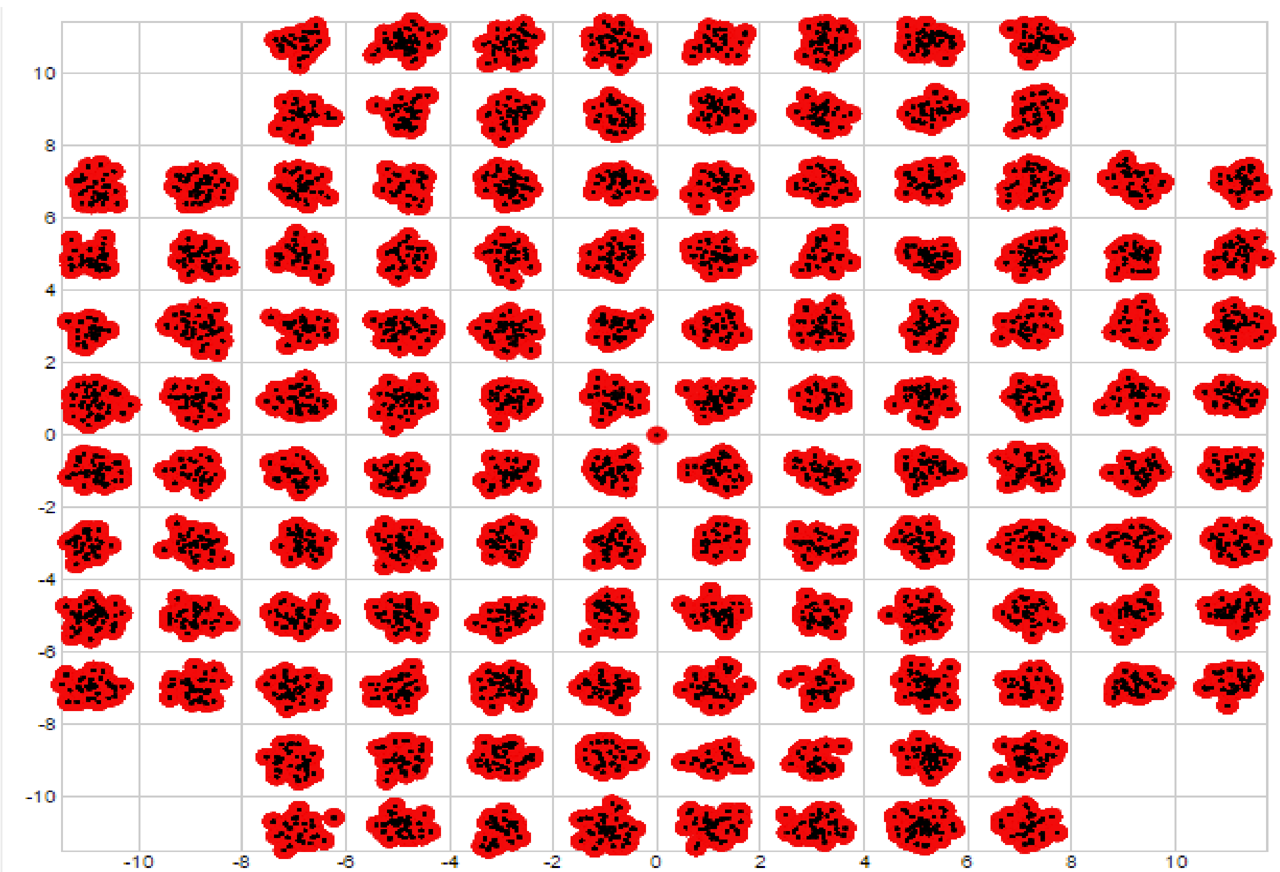

Figure-10: **Constellation Diagram at 100 Km**

Fiber losses increase significantly and non-linear impairments come into play as the distance increases, which result in a distorted signal at the receiver end. Constellation diagram for 160 Km length optical cable is shown in fig-11.

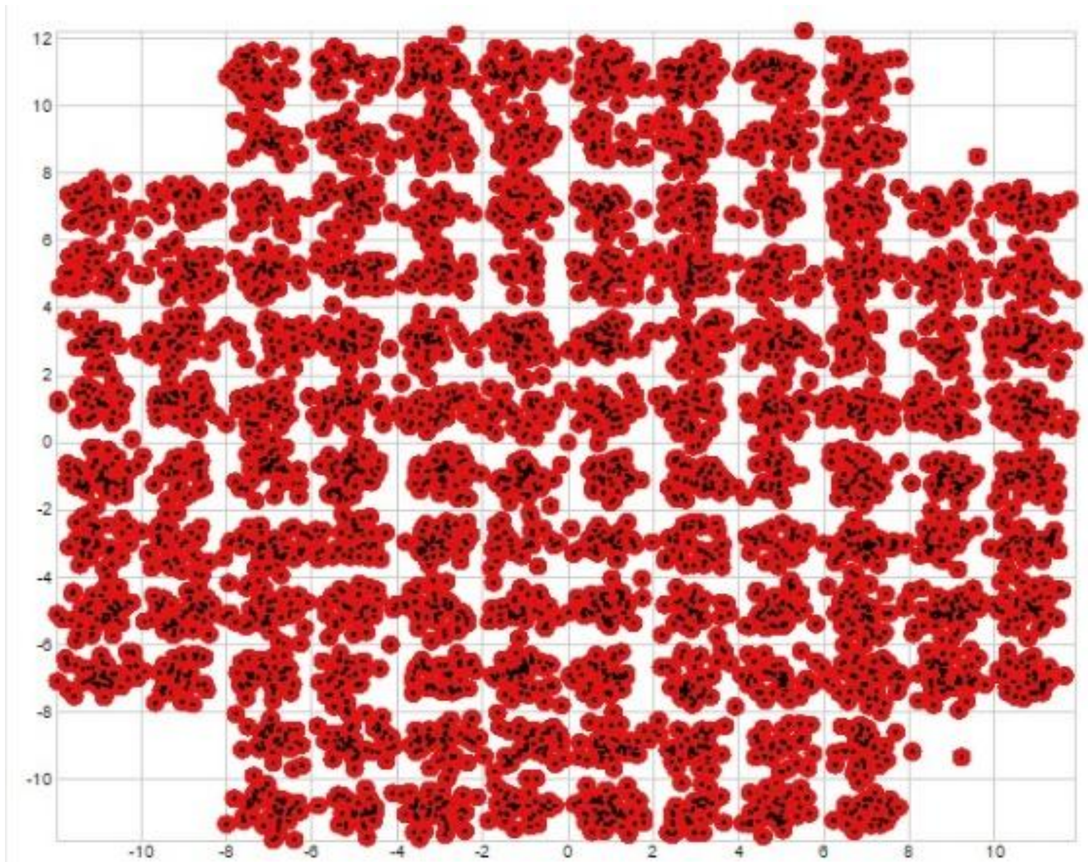

Figure-11: Constellation Diagram at 160 Km

On further increasing the distance to 220 Km, it is evident from the constellation diagram of fig-12 that the signal becomes so distorted that it is impossible to recover the original signal at the receiver end.

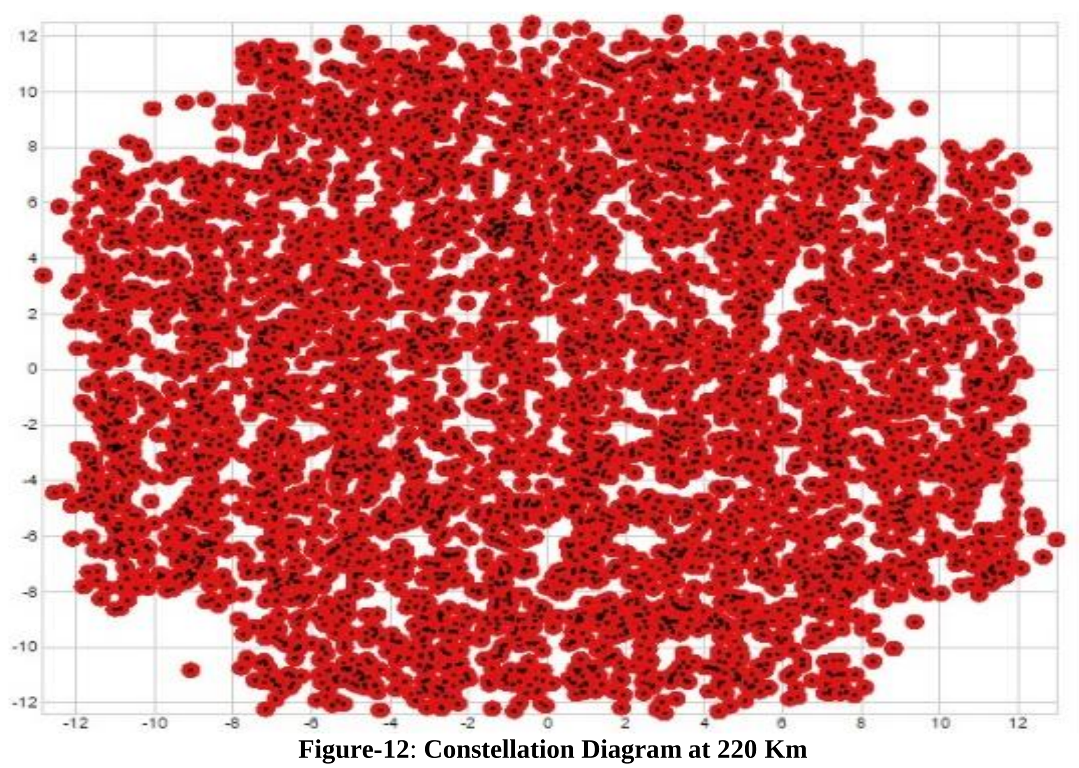

Figure-12: **Constellation Diagram at 220 Km**

Conclusions: In this research paper the performance of 128-QAM modulation technique has been analyzed. The block diagrams for both the transmitter and receiver are shown. Constellation diagrams, optical spectrum and optical signals in time domain have been observed. Different system impairments have been catered by the use of DCF and optical amplifier. Data transmission at different fiber lengths has been shown. Constellation diagrams for 160 and 220 Km length have been included as a comparison of distance effect on transmission. It indicates that it becomes difficult up to the extent of impossibility, to extract original signal from the transmitted signal at these distances. The research reveals that upper bound on the transmission capacity for various QAM options can be estimated for different distances using the model developed in this paper.

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