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A 50-GB QPSK OPTICAL RECEIVER WITH A PHASE/FREQUENCY USING DENSE WAVELENGTH DIVISION MULTPLEXING SYSTEM

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ABSTRACT

Fibre-optic communication technology has been forced to adopt the Dense Wavelength Division Multiplexing (DWDM) system as a viable solution as a result of the exponentially increasing demand for channel capacity in long-haul high-speed transmission systems. This demand has been the driving force behind the adoption of this system. Research into acceptable system design techniques that optimise the parameters associated with data transmission within the constraints of the channel characteristics has become an essential area of focus in the effort to maximise the performance of optical networks of this kind. In most cases, the optical channel capacity is affected by the form of the signal, the dispersive and non-linear features of the guiding medium, as well as interference from several different sources. This study effort studies the effect of spectrally efficient modulated systems in optical communication networks to control the linear and non-linear impairments that arise in high data rate transmission. This is done so that we may circumvent the problems that have been brought to light. Because of the rigorous limits placed on the features of the optical channel, it is necessary to have an effective DWDM optical communication system that incorporates a careful selection of the modulation format and pulse shape. The use of modulation formats like intensity and phase modulation formats has developed as a viable technology that allows the design of such networks to operate to the designer's satisfaction. The purpose of this dissertation is to gain an understanding of how different system components and applied modulation formats affect the performance of the complete system by discussing the theoretical aspects of various models that are used in the analysis and simulation of high-speed optical communication links.

Keywords:

Dense Wavelength Division Multiplexing (DWDM), long-haul high-speed transmission systems, linear and non-linear impairments

1. INTRODUCTION

Transmission of high speed data rate with super dense wavelength division multiplexed (SDWDM) networks requires large bandwidth to maintain long distance communication. The optical fiber is the only transmission medium to fulfill the requirement of enormous bandwidth for current transmission medium [1]. Some time before, implementation of optical fiber was not feasible in communicatonl use, due to the high attenuation but currently available optical fiber has low losses due to revolutionary discoveries in optical fiber, making it suitable for transmitting multi-terabit and bandwidth efficient applications [2]. With the development of optical fiber, modification was also required in optical components to minimize the loss during the communication process. It is essential requirement of a new technology in these components. Thus optical sources and optical detector acceptable in size with amplifier were designed and fabricated [3].

For proper utilization of bandwidth, super dense wavelength division multiplexing (SD-WDM) systems allow parallel transmission of more than 200 wavelengths of 10 Gbps in the C band and L band spectra. However, using the complementary method, the capacity of the transmission signal can be further increased using the hybrid optical amplifier [4]. The development of multiplexing technology (WDM) was proposed around 1980s with sufficient channel space [5]. After 1990s, new era was initiated, which explored the transmission capacity with more than six optical channels. This is known as era of short band system because the channels were arranged with channel spacing of 12.4 GHz. In fact, channel spacing was a big issue in those days to maintain better communication with least losses; and that was somehow covered by using the guarding band between the channel spacing. In the beginning of 1990s the requirement of channel capacity was developed, which was initiated to develop dense multiplexing system with 35 to 60 channels with the channel spacing from 100 GHz to 200 GHz. At the end of 1990s, an era of optical communication was started with capacity of 80 channels to 200 channels, with the support of 50 GHz channels spacing [6-7].Optical fiber communication is a remarkable technology for the current communication medium, to fulfill the requirement of all aspects of dense transmission signal [8]. In the optical fiber communication system, the analog and digital signals are transmitted through the optical fiber.

As they propagate through the optical fiber, the signals get attenuated due to the presence of fiber nonlinearity and other dominating losses. So it can be overcome either by a regenerator or an optical amplifier at a specific point along the length of the fiber. But regenerator, which is an optoelectronics device is a complex and time consuming process for the SD-WDM system. The requirement of optical amplifier is emphasized for upgrading a super dense network for long haul optical communication system without using (O-E-O) conversion [9]. Optical amplifiers are the backbone of the current technology, which boost the level of the signals either by placing after the transmitter (post-amplifier) or in medium (in-line amplifier) or near the receiver side (preamplifier).

The nonlinearity are the main issues in high capacity super dense optical communication systems, which can be overcome by implementing the optical amplifiers and the final outcome is represented in terms of acceptable characteristics (gain flatness, bit error rate, quality factor, larger gain bandwidth, crosstalk etc.) for SD-WDM system. In order to attain the best rating aspect, it is utmost important to design and optimize the most prominent optical amplifier for communication systems.

In fact, the requirement of super dense communication technology cannot be fulfilled using the individual commercial optical amplifier due to the limiting output rating [10]. So hybrid optical amplifiers (HOAs) are the most promising and advanced technology for justifying itself in all the aspects, for the current revolutionary communication technology without using any cost effective technique. The other existing technologies, other than hybrid optical amplifiers, have some drawbacks in terms of crosstalk, transient response and noise from the other sources, which should be considered for betterment of the best rating optical communication. The performance of HOA has shown better outcome in terms of broadband amplification, overcoming the effect of nonlinearity, maintaining the output power, enhancing the gain and quality factor with least variation and can be used without costly components like gain flattering filters and multi-pumps for the gain flatness process [11].

1.1 OPTICAL AMPLIFIERS

1.1.1 THE MAIN ROLE OF OPTICAL AMPLIFIERS

As compared to regenerators, the optical amplifier doesn't require O-E-O conversion to boost the level of optical signal [12]. In fact, it is a time consuming process, regenerator is amplified and cleans up the optical signal in three steps. In the first step of the process, the received optical signal is converted to electrical domain and then amplified; in the second step of the process, the signal is cleaned up of the pulses using re-timing and re-shaping circuits, and in the third step of the process, the signal is re-converted in optical domain and amplified for the further process. The large bandwidth of the optical amplifiers provides the platform for super dense systems for propagating multiplexing channel at a time, and supports to transmit high speed data rate. Furthermore, due to acceptable gain with less nose figure, it is capable to maintain feasible quality fact, bit error rate and some other acceptable aspects for optical communication [13].

2. RESEARCH SURVEY

In this chapter, we present systematic literature review of Hybrid optical amplifiers (HOAs). Optical signals booster are the main component in super dense optical communications systems. They play the main role to counteract the internal losses, the nonlinearity induced by optical fiber, cross talk and power losses at the splitter and coupler side [13]. In this way, optical amplifiers give a strong benchmark for optical communication systems, to maintain the long haul optical transmission with minor effects of bit error rate, noise figure and other dominating effects. In the absence of these amplifiers, boost up of the optical signal is quite tricky and time consuming process. Signals have to go through the (3R) process. In fact, other techniques of signal transmission are quite complex and more power consuming, subsequently it delivers the unwanted load over the users to opt it [30]. The optical communication system with the hybrid optical amplifier is quite supporting and easy handling process, which is capable of providing the required gain bandwidth to the transmission system.

Optical amplifiers show various advantages over the optical regenerator, in terms of flexibility of operating system, transmission of multiple channels with different data rate and no use of extra components for inline medium for cost effectiveness. All these characteristics support a super dense optical communication system to attain the required outcome for the betterment of communication processes [31]. Both optical amplifiers such as EDFA and RAMAN have shown novel performance in SD-WDM system but use of them as hybrid optical amplifier is also not a cost effective solution. The burden of increasing number of channels on super dense network can only be satisfied using hybrid optical amplifier technology for the better outcome. Indeed, the main reason to recommend the hybrid amplifier is to enhance the system performance by providing a huge bandwidth to the SD-WDM system, neglecting the effect of nonlinearity and avoiding the use of gain flattening with multi-pumping power . But there are many issues present in hybrid optical amplifiers in terms of gain flatness, crosstalk, transient response, gain bandwidth product, and long haul super dense optical communication, which must be resolved before implementing in the medium for the required aspect.

In SD-WDM system, many challenging issues exist, which affect the performance of the system and the final outcome comes out with unsatisfactory representation.

2.1 MAJOR ISSUES IN PRESENT RESEARCH

A novel revolution has been observed in optical communication because of increasing demands of high speed internet and different multimedia services. High speed data transmission with the conventional optical amplifiers is not possible due to their limiting aspects so hybrid optical amplifiers are the right consideration to fulfill all the requirements for the future super dense optical communication system. As per the literature review, it is known that hybrid optical amplifiers are the best consideration to neglect the effect of fiber nonlinearity and induced crosstalk in a super dense system.

In order to maintain better communication, it is utmost important to propose and design suitable hybrid optical amplifier to mitigate the effect of unwanted features of communication process. Based on the above literature review, the major issues in present research have been summarized as below:

1- Performance investigations of hybrid optical amplifier with reduced channels spacing is required.

2-There is major scope to attain best rating parameters for super dense optical communication system.

3-There is need to examine the position of the system for different spectrum (C-band, L-band) for getting acceptable rating flat gain and noise figure.

4-Impact of hybrid optical amplifier for long haul optical communication system is also an important consideration.

5-The performance investigation of HOA for SD-WDM is not considered till now.

6-The investigation of suitable parameters for super dense system in terms of long haul optical communication is required.

7-There is scope to analyze the effect of imbalance of power among the super dense channel.

2.2 PROPOSED OBJECTIVES

As per the major issues present in hybrid optical amplifier, the following objectives have been recommended for the betterment of super dense optical communication system.

1-To design hybrid optical amplifier for higher gain bandwidth product for super dense wavelength division multiplexing system with narrow channel spacing.

2-To optimize hybrid optical amplifiers for super dense wavelength division multiplexing system in terms gain and noise figure.

3-To analyze the performance of dynamically flattened gain Long Band using HOA for SDWDM system.

4-To investigate the crosstalk effect for proposed hybrid optical amplifier with different spacing and transmission distance of optical fiber for super dense wavelength division multiplexing system.

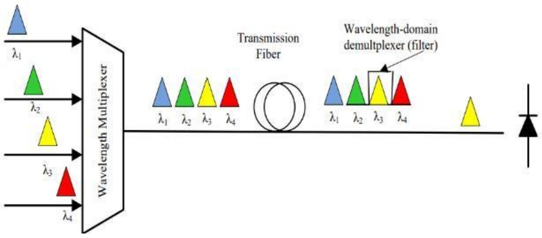

Fig. 2.1: Generalized 4-channel UDWDM system

First, a DQPSK modulated four-channel 25 GHz spaced network similar to the one illustrated in Figure 1 is created. Next, the number of channels is progressively expanded to eight, then sixteen, and finally to thirty-two. Following this, the performance of this 32-channel 25 GHz spaced system is compared with that of a 50 GHz spaced link at various power levels to provide a comparative analysis of the maximum distance that can be achieved. This comparison is based on the Q value and eye-opening for multiple transmission spans that can be achieved by varying the input power of a signal. In this research, we investigate how altering the channel spacing and the number of channels has an impact not only on the Bit Error Rate (BER) but also on the XPM.

To arrive at the generalised forms of fibre non-linearity-induced distortions, it is anticipated that a multi-segmented, optically amplified UDWDM system model would be used. We look at chromatic dispersion as a single lump of distortion that occurs after each span and is adjusted for by the dispersion correction element. This is done under the assumption that there is no PM-IM conversion occurring. It is generally accepted that only XPM and loss are spread evenly over the length of the fibre. The degree of XPM degradation is affected by a variety of characteristics, including walk-off between neighbouring channels, individual channel power, nonlinear fiber coefficient γ and the modulation format that is being used [26]. The nonlinear fibre coefficient is another parameter that plays a role. To prevent the system from being affected by SPM-induced nonlinearities, the signal launch power is set at a sufficiently low level. A reduction in the deterioration caused by Group Velocity Dispersion may be achieved by the use of suitable Dispersion Compensating Fiber (DCFs) in the fibre connection (GVD).

Because the imposed phase shift directly impacts the received signal, phase-modulated systems are very susceptible to the non-linearities that might occur in fibre. The ASE noise that is produced by optical amplifiers is the primary cause of variations in intensity. This noise also produces nonlinear phase noise in long-haul multi-span systems. This model is predicated on the observation that dispersion causes a certain amount of bits to go across the neighbouring DQPSK channel, which results in the XPM-induced phase shift being dependent on the bit pattern. The frequency difference Δv between the channels can be calculated using the formula $LD\lambda\ 2\Delta u/c$, where D is the dispersion parameter, is the optical wavelength, L is the length of the fibre, and c is the speed of light. A frequency difference between the channels of v corresponds to a typical time difference of Δt. NW is defined as the number of walk-of bits that travel from a certain point of the DQPSK signal throughout the whole of the fibre length.

NW = t.B,

Where B is the bit rate and is denoted by the notation "n".

As a result of taking this into account, the standard deviation of the DQPSK phase shift at the receiver side may be calculated. Both DCF and SMF have the same NW in a system that accounts for dispersion in its entirety; nevertheless, the signal power level and the direction of passage differ between the two.

3. SIMULATION RESULTS AND DISCUSSION

At first, a four-channel DQPSK modulated 25 GHz spaced system is constructed, and then its performance at 0 dBm power level is examined. We decide on the values for the DCF and SMF parameters to achieve an accurate compensation for the first-order dispersion (D = 0), which is written as $D_{SMF}L_{SMF} = D_{DCF}L_{DCF}$. After afterwards, there was a slow but steady growth in the total number of channels until it reached 32. It provides a comparative analysis of the Q factor seen concerning the greatest distance travelled by the optical signal across a variety of channel spacing configurations. This analysis is presented in the form of a table. According to the dependence that has been laid out in the table, there will be an increase in the amount of crosstalk that occurs during transmission if a higher number of nearby channels are used. Although the beginning Q value is almost exactly in the same range for all four instances, the transmission distance is around 1800 km for four channels but only 900 km for a 32-channel scenario, which is a strong indication of the rise in XPM-induced crosstalk.

The proposed 32-channel UDWDM system is simulated for the ideal case, in which there are no nonlinearities, by setting the non-linear coefficient, to zero at a constant power level of 0 dBm. This ensures that the system will function properly in the absence of nonlinearities. where it is contrasted with the performance of a system that takes into account non-linearities. Since the primary objective of the work is to investigate the impact that nonlinear impairments have on a UDWDM system, we made sure to account for nonlinear constraints in all of our subsequent research.

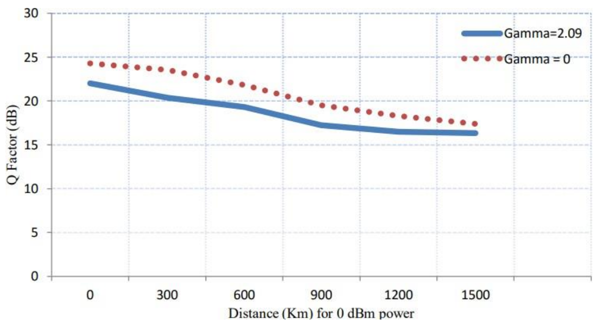

Fig.3.1. System performance comparison in the absence and presence of nonlinearities.

Additional research has been conducted, and the 32-channel system has been examined for a variety of input power levels. The performance of both 50 GHz and 25 GHz spaced DQPSK systems is shown graphically in terms of the Q value as a function of transmission distance. The SPM-induced phase modulation to intensity modulation conversion that occurs via fibre dispersion was brought to light when it was found that the eye-opening penalty increased for extremely strong transmitted power. SPM expands while simultaneously depleting the signals as the power is increased. Therefore, power grows up to the point when non-linearity prevails over chromatic dispersion, which indicates that signal deterioration is beginning to take place. After this point, power decreases. On the other hand, when the input powers are low, a noticeable improvement in the system's performance may be seen. Therefore, to restrict the non-linear effects of a high data rate WDM system, the input power should be as low as it can be; for this reason, we adjust the input power between -5 dBm and 5 dBm. Fig. 6 (a) reveals that for very low power levels of 0 dBm power

Gamma=2.09 Gamma = 0 -5 dBm, the 25 GHz DQPSK modulated system can run for 10 spans, which is equivalent to a distance of 600 km, while the 50 GHz system achieves a transmission distance of 900 km. These results are for very low power levels of 0 5 10 15 20 25 30 0 300 600 After the first span, the initial Q value for the 50 GHz case is 20 dB, whereas the first Q value for the 25 GHz case is 18 dB. The curves overlap between 500 and 700 kilometres, which indicates that both scenarios have equal performance.

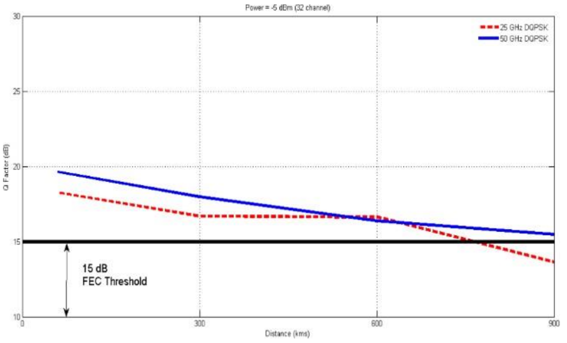

Fig.3.2a

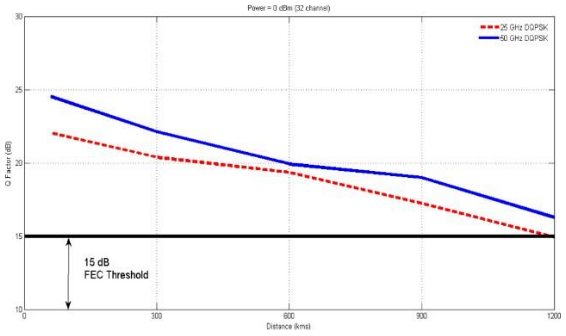

Fig.3.2b

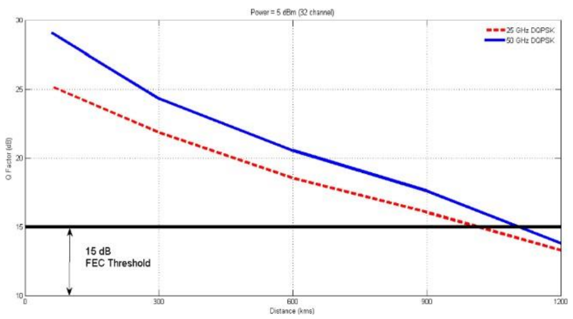

Fig.3.2c

Fig.2: Q value as a function of transmission distance for (a) Pin = -5 dBm (b) Pin = 0 dBm (c) Pin = 5 dBm

The Q value may reach up to 26 dB at an initial launch power of 1 dBm, and it operates very well over distances more than 1200 kilometres; nevertheless, the curves do not closely follow each other. The 50 GHz system outperforms the 25 GHz one from the first span with a starting Q value close to 30 dB as compared to 26 dB for the 25 GHz case and maintains its superiority up to 1100 Km, while the 25 GHz system falls below the threshold at 1000 Km only. This is the case for the 5 dBm launch power case as shown in Figure 2(c). The maximum transmission distance of one thousand kilometres is achieved in both scenarios.

After adjusting the simulation settings, the numerical results reveal that DQPSK may achieve a maximum reach of 1500 kilometres with a bit error rate (BER) of at least 10-9 in the optical route of a 40 Gigabits per second (Gbps) transmission system with 25 Gigahertz (GHz) channel spacing. Inter-channel interference is dramatically reduced when the distance between channels is increased. When using DQPSK, a channel spacing of 50 GHz has the potential to provide an increase in reach of up to 40%. The performance of the system is improved by RZ-DQPSK, albeit at the expense of the complexity of the transmitter. When compared to the case of 25 GHz, the performance of the 50 GHz system is, without a doubt, superior; nevertheless, even for the 25 GHz instance, the Q value remains over the FEC threshold for up to 1000 kilometres, which is an intriguing finding.

4. CONCLUSION

The work presented here effectively proves the transmission of 32 DQPSK modulated channels across a distance of up to 1500 kilometres in the presence of a variety of simulated fibre nonlinearities. The OptiSystem trans-receiver model is being created to assess the comparative transmission performance characteristics of the proposed UWDM systems that are operating at channel spacings of 25 GHz and 50 GHz, respectively, at a variety of input power levels. The simulation research that was done on the data demonstrates that DQPSK modulation is superior in terms of reducing the amount of crosstalk that occurs when signals are being sent. In addition to this, it excels at greater launch powers as a result of its improved spectral efficiency, which enables it to endure degradations brought on by dispersion. An experimentalist may benefit from the findings of the current investigation by better visualising the myriad of complications that are associated with high-speed lines according to the findings. Despite this, the options for selecting the optimal fibre to transmit DQPSK-modulated signals with variable duty cycles are still available for consideration. Because relatively few tests on UDWDM systems have been carried out up to this point, the basic limiting issues and the solutions to these problems in such systems are not well defined. This is particularly the case when transferring data at a rate that is greater than 40 Gb/s. Therefore, it can be deduced that to cope with optical non-linearity-induced penalties, significant chromatic dispersion and polarization-mode dispersion constraints first need to be addressed at these data rates. In comparison to BPSK, the PMD tolerance of QPSK is much higher. Nevertheless, it is not immune to the polarisation limitation's effects. Utilizing coherent detection for each of the subcarriers is one method that may be used to get around this issue. This technique calls for the use of four highly steady receiver lasers as the local oscillators, which is a somewhat pricey solution. In the future, it may be possible to investigate the possibility of integrating coherent technology based on PM-QPSK, PS-QPSK, PM-16 QAM, and DP-QPSK with UDWDM. This is possible because the utilisation of DSP makes the equalisation of transmission impairments and the implementation of forward error correction less stringent requirements.

References

1. Shilpi Verma and Sanmukh Kaur, (2021),Performance analysis of differential quadrature phase shift keying modulation schemes for a radio over fiber system, Journal of Optical Technology, Vol. 88, Issue 6, pp. 297-307
2. Guan, Xun & Shi, Wei & Rusch, Leslie. (2021). Ultra-Dense Wavelength-Division Multiplexing With Microring Modulator. Journal of Lightwave Technology. PP. 1-1. 10.1109/JLT.2021.3070515.
3. V. Tavassoli, "High Capacity Phase/Amplitude Modulated Optical Communication Systems and Nonlinear Inter-Channel Impairments", Phd Thesis, University of Victoria, 2012.
4. Lucky Sharan, Vaibhav Madangopal Agrawal, & Vinod Kumar Chaubey. (2016). link optimization and performance analysis of a 40 gbps dqpsk modulated ultra dwdm system with 32 orthogonally polarized channels. *Journal of Microwaves, Optoelectronics and Electromagnetic Applications (JMOe)*, *15*(4), 349–364. https://doi.org/10.1590/2179-10742016v15i4715
5. Agarwal, R., Bhatia, R. All-optical modulation format conversion between 16-PSK and 8-PSK in elastic optical network. *Opt Quant Electron* **55**, 160 (2023). https://doi.org/10.1007/s11082-022-04413-0
6. D. Wang, J. Zhang, G. Gao, X. Cheng, S. Chen, Y. Zhao and W. Gu, "Pulse broadening factor as a criterion to assess nonlinear penalty of 40-Gbit/s RZ-DQPSK signals in dynamic transparent optical networks", Optical Fiber Technology, Vol. 17, pp. 305–309, 2011
7. Naif Alsowaidi 1,*, Tawfig Eltaif 2,* and Mohd Ridzuan Mokhtar, Performance Comparison of Different Modulation Formats for a 40 Gbps Hybrid Optical CDMA/DWDM System against ISI and FWM, Photonics 2022, 9, 555. https://doi.org/10.3390/photonics9080555
8. C. R Silveira, D.M. Pataca, M.A. Romero and M. L Rocha, "A Cost-Benefit Analysis on Modulation Formats for 40-Gb/s Optical Communication Systems", Fiber and Integrated Optics, Vol. 30, No. 2, pp. 87-101, 2011
9. L. Lia, J. Zhang, D. Duana and A. Yin, "Analysis modulation formats of DQPSK in WDM-PON system", Optik (Elsevier), Vol. 123, pp. 2050-2055, 2013.
10. Hsu, Ching-Hsuan & Jiang, Syu-Yang & Hsieh, Shang-En & Yeh, Ching-Hua & Lai, Yu-Ting & Chen, Lan-Yin & Liaw, Shien-Kuei & Chow, Chi-Wai. (2022). Hybrid Self-Protected Fiber-

FSO WDM-PON System with Fiber Breakage Prevention. Photonics. 9. 822. 10.3390/photonics9110822.
11. S. Ghoniemy, K.F. George and L. MacEachern, "Performance evaluation and enhancements of 42.7 Gb/s DWDM transmission system using different modulation formats", Ninth Annual Communication Networks and Services Research Conf., pp. 189–194, 2011.
12. D. Wang, D. Lu, C. Lou, L. Huo and W. Yu, "Performance comparison of phase modulated formats in 160 Gb/s transmission system", IEEE Communications and Photonics Conference, ACP, Asia, pp. 1- 6, 2011
13. E. Lach and W. Idler, "Modulation formats for 100G and beyond", in Optical Fiber Technology, Vol. 17, pp. 377–386, 2011.
14. https://www.sciencedirect.com/topics/engineering/coherent-detection-system
15. J. Renaudier, O. Bertran-Pardo, G. Charlet, M. Salsi, H. Mardoyan, P. Tran and S. Bigo, "8 Tb/s long haul transmission over low dispersion fibers using 100 Gb/s PDM-QPSK channels paired with coherent detection", Bell Labs Technical Journal, Vol. 14, No. 4, pp. 27–45, 2010.
16. B. Zhu, D. W. Peckham, X. Jiang, and R. Lingle Jr, "System performance of long-haul 112-Gb/s PDM-QPSK DWDM transmission over large-area fiber and SSMF spans", 39th European Conference on Optical Communication (ECOC), 2013.
17. J. Karaki, E. Pincemin, D. Grot, T. Guiliossou, Y. Jaouen, R. le Bidan and T. le Gall, "Dual_polarization multi-band OFDM versus single–carrier DP-QPSK for 100 Gbps long-haul WDM transmission over legacy infrastructure", 38th European Conference on Optical Communications (ECOC), 2012.