Performance of DQPSK, NRZ and RZ modulation formats in different optical fibres

H. C. Cherutoi, K. Muguro, D. W. Waswa, and G. M. Isoe

***Abstract*—** With the development of high-speed, long distance optical fibre communication systems, linear factors become one of the important factors limiting high-speed, long distance optical fibre transmission. This linear effect includes attenuation, polarization mode dispersion (PMD), Chromatic dispersion (CD) and optical signal to noise ratio (OSNR). In this paper, theoretical investigation has been done on the performance of Single Mode Fibres (SMFs) namely standard (SSMF), Large Area (LA), Reach (R) and Reduced Slope (RS). The performance of Return to Zero (RZ), Non Return to Zero (NRZ) and differential quadrature phase shifting keying (DQPSK) were also compared in different fibre types at bit rate of 10 Gb/s. The effect of variation in system length, dispersion and core effective area is observed in terms of bit error ratio (BER) and quality (Q) value. The power penalty suffered by the system is evaluated at BER= 10^{-9} threshold for SMF operating at 1550 nm. The Q factor was used to evaluate the performance of the system at a BER= 10^{-9} which corresponds to a Q factor of 6. It is found that SSMF has the highest BER and lowest Q factor values. It is also found that BER and Q factor performance of the system is highly dependent on fibre length, core effective area and dispersion parameters. DQPSK has better performance than NRZ and RZ modulation formats.

Key words – BER, Chromatic dispersion Q-factor

I. INTRODUCTION

In order to support dramatically increasing data traffic demand, high-capacity optical backbone networks are needed. However upgrading of fibre telecommunication systems to higher bit rates often requires solving the impact of linear degrading factors [1]. For transmission rates of 10 Gb/s per channel and higher, the use of more advanced formats is necessary and the design of new modulations formats is expected [2]. This requires detailed knowledge of performance efficiency of modulation formats, as well as the clear specificificatios of shortcomings to be solved while proposing new solutions.

The optical modulation is the main issue which has much influence on the transmission quality and spectral efficiency. Modulation is the process of varying some parameters of periodic waveform in order to use that signal to convey a massage [3]. In single mode optical fibres, the optical field has three physical attributes that can be used to carry information: intensity, phase (or frequency) and polarization.

Depending upon which of the three quantities is used for information transport, we distinguish between intensity, phase (or frequency) and polarization data modulation formats. The simplest optical modulation format is on-off keying (OOK) intensity modulation, which can either take two forms: Non Return to Zero (NRZ) or Return to Zero (RZ). Earlier, RZ and NRZ was the main modulation format in optical systems [4].The demand for high transmission capacity lead to the creation of new modulation formats. Differential quadrature phase shifting keying (DQPSK) is a recent modulation format for highly-capacity transmission links [5]. However; this modulation format is limited by fibre linearities in long haul optical links. In this paper we have investigated the performance of RZ, NRZ and DQPSK modulation formats in 10 Gb/s passive optical networks (PON). PONs is characterized by sharing one optical laser among several end users. The overall system performance of a communication link is quantified by analyzing two important parameters namely BER and Q-factor at the receiver sensitivity [6]. The receiver sensitivity relates the amount of optical power needed to obtain the minimum BER. In order to transmit signals over long distances, it is necessary to have a low BER and high Q factor within the fibre [7].BER is the ratio of the number of bit errors detected in the receiver to the number of bits transmitted. For example, a transmission having a BER of 10^{-6} means that out of 1,000,000 bits transmitted, one bit is an error. An error happens as a result of incorrect decision being made in the receiver due the presence of noise on a digital system. The decision to sample and whether the sampled value represents a binary 1 or 0 is affected by noise and signal distortion in the real system and there is nonzero probability of an erroneous decision. Therefore the received signal quality is directly related to the BER, which is a major indicator of the quality of the overall system. BER is affected by attenuation, noise, dispersion, crosstalk between adjacent channels or jitter. Its performance may be improved by launching a strong signal into a transmission system. BER is given by the following expression

$$BER = \frac{1}{2} erf\left(\frac{Q}{\sqrt{2}}\right) \approx \frac{\exp\left(\frac{-Q^2}{2}\right)}{Q\sqrt{2\pi}} \qquad (1)$$

Where the Q-factor is given by the following equation [8].

$$Q[-] = \frac{\mu_1 - \mu_0}{\sigma_1 + \sigma_0} \qquad (2)$$

Where μ_1 is the value of the binary 1, μ_0 is the value of the binary 0, σ_1 is the standard deviation of the binary 1 and σ_0

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is the standard deviation of the binary 0. Generally, the BER decreases as the Q-factor increases. Higher value of the Q-factor means a better signal to noise ratio (SNR) and therefore a lower BER. For a Q-factor ranging from 6 to 7, the BER is obtained as of 10^{-9} up to 10^{-12}.

II. METHODOLOGY

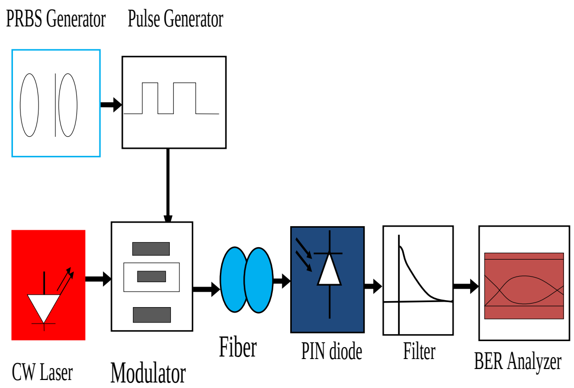

Fig.1: Simulation set up of optical communication system

Optical communication system performance can be obtained by analyzing the received signal. In this research, an optical communication system was developed using OptiSystem software (7.0) platform. The system consisted of a transmitter, a transmission channel and receiver. The transmitter consisted of continuous wave laser (CW), pseudo random bit sequence generator (PRBS), pulse generator and a modulator. Single mode fibre (SMF) was used as a transmission channel. The receiver consisted of positive-intrinsic-negative (PIN) photo diode, low pass optical filter and bit error rate (BER) analyzer. A laser of wavelength 1550 nm and 2dBm optical power was launched into the fibre. It was then modulated using pseudo-random data generator (PBRS) at a bit rate of 10 Gb/s. The signal was then transmitted through SSMF, R, LA and RS fibres at 60km length with an attenuation of 0.2dB/km. The optical signal was then converted electrical signal via PIN photo diode. The low pass filter was then employed to reduce noise. The filtered signal is analyzed for the Q- factor and BER.

III. RESULTS AND DISCUSSIONS

Table 1. BER and Q- factor simulated values for various digital modulations.

Modulation format	BER	Q-Factor
DQPSK	-13.04	19.48
NRZ	-2.42	17.17
RZ	0.19	7.20

The performance of digital modulation formats are analyzed on the basis of Q-factor and BER. The CW laser, bit rate and fibre length are kept constant at 2dBm, 10 Gb/s and 60Km respectively. Table 1 shows BER and Q-values for various digital modulations. From the analysis, it is observed that DQPSK modulation provides better Q factor and low BER.

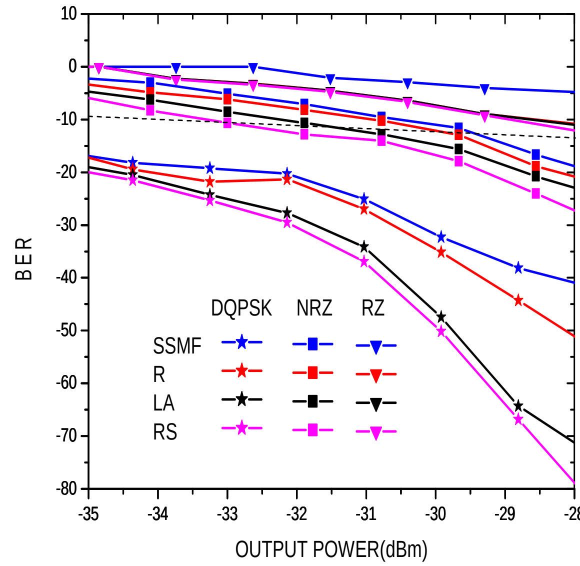

Fig. 2: Variation of BER with the Output Power for different fibres at 60KM length at a transmission rate of 10 Gb/s.

According to Figure 2, there is a decrease in BER as the output power increases, thus showing that the signal integrity improves as the output power increases. This is because at low output power, the system is limited by linearities resulting to signal attenuation hence high bit errors. It should be noted that the BER values for RZ modulation format is higher than that for DQPSK and NRZ modulation formats. DQPSK performs better than NRZ and RZ modulation formats. This is because DQPSK is tolerant to CD and PMD and therefore it can transmit optical data to greater length without errors i.e. all the four types of fibres in DQPSK modulation format namely; SSMF, LA, R and RS are below the acceptable bit error of 10^{-9}. However in NRZ modulation, a minimum power of -33.7 dBm, -32.8 dBm, -31.8 dBm and -31.2 dBm for RS, LA, R and SSMF fibres respectively is required at the receiver to achieve BER value of 10^{-9}. Higher BER values were obtained in RZ modulation because of wider optical bandwidth and as such it is more affected by dispersion.

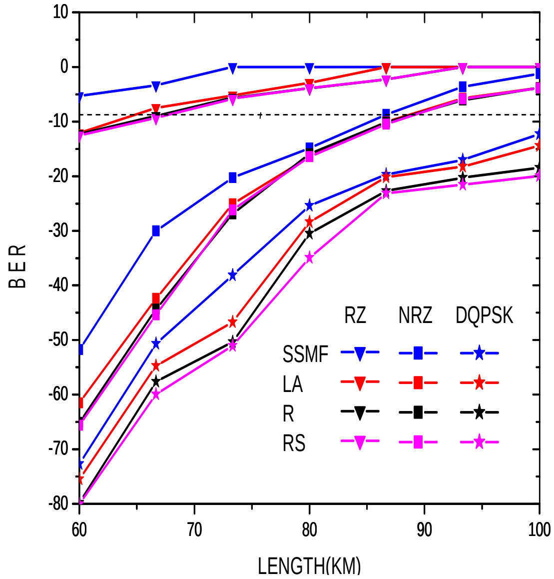

Fig. 3: BER verses length at a transmission rate of 10 Gb/s and 2dBm input power

From fig. 4, it can be seen that all the modulation formats experience an increase in BER as the length of the optical fibre is increased. This means that the errors in the output signal increases. When the distance between the transmitter and the receiver increases, the attenuation go on increasing and this reduces the received power at the output leading to more errors. It can be seen that DQPSK has better performance than NRZ and RZ modulation formats. Data is transmitted to greater lengths of up to 100KM without an error. This is because at 10 Gb/s, DQPSK Modulation format is tolerant to linear effects i.e. CD, PMD and OSNR making it suitable for long haul transmission. In NRZ modulation format, RS, LA and R fibres transmit data up to 90KM without an error. However for SSMF, the maximum length achievable is 86KM at BER of 10^{-9}.This is due to higher dispersion in the fibre which limits the transmission distance. For RZ Modulation format, optical data can be transmitted to a length of approximately 65KM without an error using LA, R and RS fibers. However for SSMF at 60KM fibre length, the BER is above the 10^{-9} threshold value.

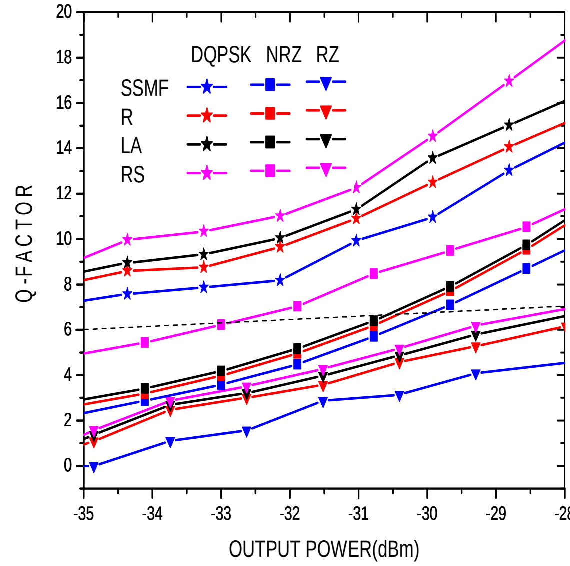

Fig. 4: Shows the variation of the output power with the Q Factor for a 60KM fibre length at a transmission rate of 10 Gb/s

From fig 4, the Q-factor increases with the increase in the output power at the receiver. The Q-factor is widely used to specify the performance of a system and at a BER= 10^{-9} corresponds to a minimum Q-factor of 6 and this is the most used value in most telecommunication systems. It can be seen that low Q value corresponds to lower output power and this is because at lower power, the system error increases due to dispersion and attenuation in the fibre which decreases the Q-factor of the system. We can observe low Q values for RZ modulation format followed by NRZ and finally DQPSK modulation formats. The Q-factor of RZ Modulation is below 6 at the output. It can also be seen that in RZ modulation format, SSMF has the lowest Q values. For NRZ Format, a minimum power of -33.5 dBm, -31.5 dBm, -31dBm and 29.5 dBm is required for RS, LA, R and SSMF fibres respectively to achieve the Q factor of 6 i.e. at BER= 10^{-9}. However, all the fibre types in DQPSK modulation operate in error free region i.e. the Q value is above the minimum threshold value of 6.This is because DQPSK exhibits higher dispersion tolerance at greater lengths.

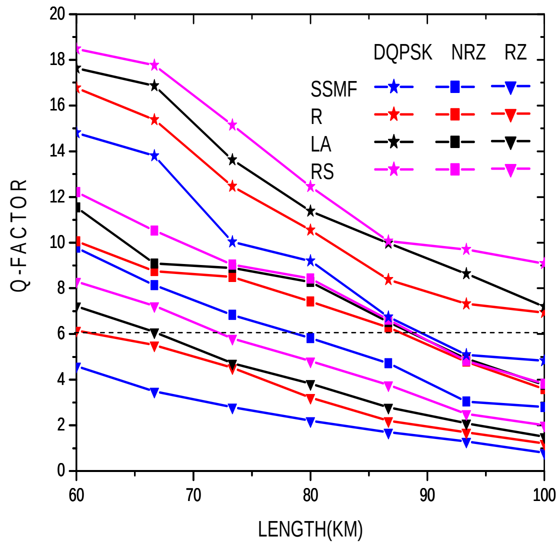

Fig. 5: Q-Factor verses length at a transmission rate of 10 Gb/s and 2 dBm input power

From Fig. 5, it can be seen that as the distance increases, the Q factor decreases. This is because as the length of the fibre increases, PMD degrading factor becomes more significant hence leading to signal distortion therefore lowering the quality of the signal. DQPSK has better performance than NRZ and RZ modulation formats. Data is transmitted to greater lengths of up to 100KM without an error using RS, LA and R fibres i.e. the Q-factor is above 6 which is below BER=10^{-9} threshold. This is because at 10 Gb/s, DQPSK Modulation format is tolerant to linear effects making it suitable for long haul transmission. It can also be noted that in NRZ modulation format, LA, R and RS fibres also transmit data to a length of 90KM without an error. However for SSMF, the maximum length achievable is 78KM at BER of 10^{-9}.This is due to higher dispersion in the fibre which limits the transmission distance. For RZ Modulation format, optical data can be transmitted to a maximum length of 72KM, 67KM and 62KM using RS, LA and R fibres respectively without an error. However for SSMF at 60KM fibre length, the BER is above 10^{-9} value.

IV. CONCLUSION

The performance of different SMFs in various digital modulation formats has been analyzed. Generally, it is noted that, SSMF has lowest Q values and highest bit errors followed by to R, LA and finally RS fibre. DQPSK modulation format operates below threshold value of 10^{-9} at 100KM fibre length. However, NRZ and RZ modulation formats requires an average minimum power of -30.5 dBm and -28.5 dBm respectively to achieve the bit error rate of 10^{-9}. Better Q-factor and low BER is achieved in DQPSK modulation format. Modulation mode of optical DQPSK has the better performance on the receiver sensitivity and transmission capacity. DQPSK modulation format has a good application prospects on the long-distance, large-capacity and high speed optical communication system.

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