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SIMULATION PERFORMANCE OF A 40 GBIT/S POLARIZATION SHIFT KEYING SYSTEM

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ABSTRACT

Polarization shift keying (PolSK) and advanced modulation formats represent the future in development of high speeds communications. In this paper the feasibility of PolSK systems combining multilevel modulation is studied. The performance of 40 Gbit/s PolSK systems is tested by a optical simulation software. Optimums values for set the signals and eye diagrams are evaluated. Furthermore numerical simulations are performed to evaluate the transmission performance of a 40 Gbit/s PolSK system, and a transmission through various optical fiber lengths is demonstrated.

Keywords: Polarization shift keying, Modulation format, Polarization, Jones vectors, Optical fiber communication

محاكاة أداء لنظام اتصالات باستخدام تناوب مفتاح الرموز المستقطب بمعدل 40 Gbit/

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الموجز

تناوب مفتاح الرموز المستقطب هو شكل للتضمين المتقدم يمثل مستقبل التطور فـي الاتـصالات ذات السرعات العالية. في هذا النص تم دراسة قابلية تنفيذ نظام اتصالات تناوب مفتاح الرموز المستقطب بدمج مستويات المتعددة. تم فحص أداء أنظمة تناوب مفتاح الرموز المـستقطب بـسرعة Gbit/s 40 بواسـطة محاكاة حاسوبية. تم تقدير كل من القيم المثلى للإشارات وإيجاد مخطط ـات العـين لمنظومـة الاتـصالات المعنية. علاوة على هذا نفذت المحاكاة العددية لتقييم أداء اتصال بسرعة 40Gbit/s و استعراض النتـائج المختلفة للنظام الاتصالات باستخدام مختلف الأطوال لألياف البصرية.

1. INTRODUCTION

The Bandwidth-distance product is a key figure-of-merit of lightwave systems. To increase the capacity of lightwave systems, increase in data-rate per channel and tighter channel spacing in dense wavelength division multiplexing (DWDM) systems are possible solution. In such high speed DWDM a system, linear and nonlinear impairments become worst. These linear impairments include chromatic dispersion (CD) and polarization mode dispersion (PMD), nonlinear impairments include self phase modulation (SPM), cross phase modulation (XPM) and four-wave mixing (FWM) [**Agrawal, 2002**].

To minimize both the linear and the nonlinear impairment over transmission fiber, an optical modulation format is needed [**Winzer, 2006**]. A modulation format with a narrow optical spectrum can enhanced spectral efficiency and tolerates more CD distortion [**Chbat, 1997**]. A modulation format with constant optical power can be less susceptible to SPM and XPM; modulation format with multiple signal levels will carry more information than binary signals and its longer symbol duration will reduce the distortion include by CD and PMD [**Kaminor, 2002**].

2. BACKGROUND OF OPTICAL SIGNAL GENERATION

The signal generation in terms of optical transmission systems can be understood as the modulation of laser source with an electrical binary signal. According to this, it can be speaking of the optical signal modulation and demodulation formats. The modulated complex electric field is given by) [**Agrawal, 2002**]

$$\vec{E}_L(t) = A_{o,L}(t)\cdot \vec{e}_L(t).\cos(\omega_L t + \phi_L(t)) \tag{1}$$

Where $A_{o,L}$ is the amplitude of the optical field, ω_L is the optical angular frequency of the light source, ϕ_L is the optical phase and $\vec{e}_L$ represents the polarization vector known as Jones-vector of the signal. These four parameters are four degrees of freedom employed for the optical signal generation. Each of these parameters can be modulated by an electrical binary base band signal q(t) [**Hodzie, 2003**];

$$q(t) = \sum_{i=-\infty}^{\infty} q_i - g(t - iT_b) \tag{2}$$

With the information coefficients $q_i \in [0,1]$ and the base band pulse shape g(t) delayed by multiples of the bit period T_b . Basically on which signal parameter is modulated, it can be distinguished between amplitude shift keying (ASK), frequency shift keying (FSK), phase shift keying (PSK) and polarization shift keying (PolSK) [**Hodzie, 2003**].

3. POLARIZATION SHIFT KEYING (POLSK)

The optical PolSK signal is generated by switching the signal polarization between two orthogonal states of polarization. The Jones vector describes efficiency the polarization of a plane wave. In this representation, the plane wave [**Yariv, 2003**];

$$E(z,t) = \mathrm{Re}\left[Ae^{j(\omega t - kz)}\right] \tag{3}$$

where A is a complex vector which lies in the x-y plane. This plane wave is expressed in terms of its complex amplitude as a column vector;[**Edward, 2005**]

$$J = \begin{bmatrix} A_x e^{j\delta x} \\ A_y e^{j\delta y} \end{bmatrix} \tag{4}$$

Notice that the Jones vector is complex vector, that is, its elements are complex number J is not a vector in the real physical space; rather it is a vector in abstract mathematical space. To obtain, as an example, the real (x) component of the electric field, we must perform the operation,

$$E_x(t) = \mathrm{Re}\left[J_x e^{j\omega t}\right] = \mathrm{Re}\left[A_x e^{j(\omega t + \delta x)}\right] \tag{5}$$

The Jones vector contains complete information about the amplitudes and the phase of the electric-field-vector components. It thus specifies the wave uniquely, if we are only interested in the polarization state of the wave, it is convenient to use the normalized Jones vector which satisfies the condition that;

$$J^* \cdot J = 1 \tag{6}$$

Where the asterisk (*) denotes complex conjugation.

Thus a linearly polarized light wave with the electric field vector oscillating a long a given direction can be represented by the Jones vector; [**Edward, 2005**]

$$\begin{bmatrix} \cos\psi \\ \sin\psi \end{bmatrix} \tag{7}$$

where ψ is the azimuth angle of the oscillation direction with respect to the x-axis. The state of polarization which is orthogonal to the state represented by equation (7) can be obtained by the substitution of ψ by ($\psi + \pi / 2$), leading to a Jones vector

$$\begin{bmatrix} -\sin\psi \\ \cos\psi \end{bmatrix} \tag{8}$$

For special case when $\psi = 0$ represents linearly polarized waves whose electric field vector oscillates along the coordinate axes, the Jones vectors are given by[**Edward, 2005**];

$$\hat{x} = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \qquad \hat{y} = \begin{bmatrix} 0 \\ 1 \end{bmatrix} \tag{9}$$

4. GENERATION OF 40 GBIT/S POLSK SIGNALS

The PolSK belong to the group of novel modulation formats targeting the suppression of nonlinear system degradation and an enhancement of the maximum transmission length in high bit rate transmission systems [Cheng, 2002].

The signal generation of PolSK signals is presented in **Figure 1**. It consists of two main stages, first stage that generates the Return to Zero (RZ) signals and second stage operate as polarization modulator. In the first modulator stage, optical RZ pulses are generated in a Mach Zehnder Modulator (MZM), which is driven by an electrically filtered RZ signal at 40 GHz. The electric RZ signal is generated by an electrical RZ coder and an additional electrical filter.

The polarization switching between adjacent RZ pulses is realized by the polarization modulation of pulses in an additional polarization modulator (PolM). The polarization state of the optical signal is adjusted to a linear polarization (angle of 45^o) at the PolM input by a polarization controller (PC). By a polarization beam splitter (PBS), a RZ signal is separated into x- and y-polarization components. The modulation of y-polarization component is realized in the phase modulator (PM). As drive signal of the phase modulator a rectangular electrical clock or an electrical bit pattern with alternating bits (1010101....) can be used. The two polarization components are joined with a polarization beam combiner (PBC). If the PM drive signal is a mark ("1") the phase of the y-polarization component will be shifted by 180^o causing a polarization switching of 90^o in the total signal polarization. This results in a pulse polarization angle of -45^o after the PBC. For a space ("0") drive signal at the input of PM, no phase modulation occurs and the total pulse polarization at the PolM output remains unchanged (45^0).

The signal detection of PolSK modulation is done with a conventional NRZ detector. Also polarization switching between orthogonal bits can be implemented as additional modulation stage in combination with various ASK-based modulation formats.

5. SIMULATION RESULTS AND DISCUSSION

Figure 2 illustrate optical spectra of 40 Gb/s PolSK signal. The alternately polarized optical spectra are broader than conventional RZ or NRZ spectra as shown in **Figure 2-a**. This can be explained by the fact that the spectrum of an alternate polarized format is a superposition of two polarization components with different optical spectra. The spectrum of x-polarization is conventional RZ spectrum as shown in **Figure 2-b**, whereas the spectrum of the y-component is a carrier suppressed returned to zero (CSRZ) spectrum due to the employed phase modulation as shown in **Figure 2-c**. This explains the side bands at 20GHz left and right of the carrier if the PM is driven with a 20 GHz clock.

The polarization state versus frequency of optical signal at end of PolSK modulator is illustrated in **Figure 3**. The azimuth angle is changed from -90^{o} to 90^{o} according to the optical signal frequency. Also the ellipticity angle is changed from 45^{o} to 45^{o} versus optical signal frequency.

For ease of visualization, polarization states are often specified in terms of the polarization ellipse, specifically its orientation and elongation. A common parameterization uses the azimuth angle (ψ) (the angle between the major semi-axis of the ellipse and the x -axis) and the ellipticity (ε), which represent the ratio of the two semi-axes) as shown **Fig.(4)**. An ellipticity of zero corresponds to linear polarization and an ellipticity of 1 corresponds to circular polarization. The arctangent of the ellipticity, χ = arctan (ε) (the "ellipticity angle"), is also commonly used. The signal polarization at end of modulator is elliptical display in **Fig.(4)**. From the ellipse, the azimuth angle and ellipticity angle are measured and they equal to 44.7^{o} and 2^{o} respectively.

The PolSK signal is tested by transmitting the signal over 30km, 60km and 90km of standard single mode fiber. Single mode fiber was chosen to minimize the influence of dispersion and the main limitation of the system as it is seen from the simulation. On the receiver side of the system, the avalanche photodiode (APD) is used to detect signals and eye-diagram analyzers to evaluate performance of communication channel.

By using the simulation software to analyze the PolSK communication system, the eye diagram of received signal is demonstrated in **Fig.(5)** for fiber length 30km, 60km, and 90km respectively. Fig.(5) show that the amplitude of received signal at fiber length of 30km is approximately four times the amplitude at fiber length of 60km. It can see that the eye diagram of the received signal at 90km length is worse as shown in **Fig.(5)**, the main reason for this being the influence of attenuation and polarization mode dispersion.

6. CONCLUSION

The investigations presented in this work focusing on 40 Gbit/s based optical transmission systems with a polarization shift keying modulation. The optimization of the system settings is performed in 40 Gbit/s single channel. The signal generation and transmission characteristics of PolSK are introduced, and fundamental signal characteristics are explained. The use of PolSK modulation format enables a significant improvement of nonlinear transmission characteristics at the cost of a slightly increased transmitter complexity used for the implementation of polarization modulation on conventional RZ pulses as shown in **Fig.(5)**. In other words the transmission of data is valid for longer distance rather than using RZ modulation format.

The modulation formats employing polarization switching between consecutive pulses are identified as best solution for the performance enhancement in 40 GB/s single channel based transmission lines.

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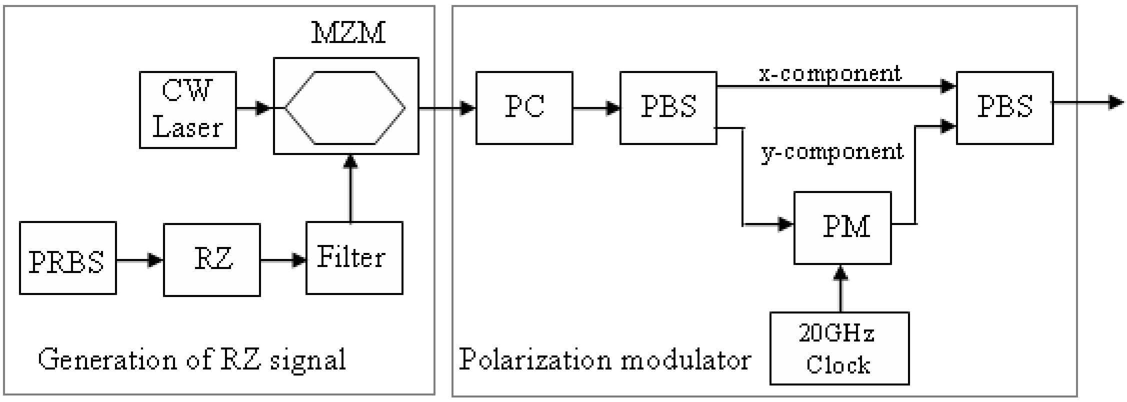
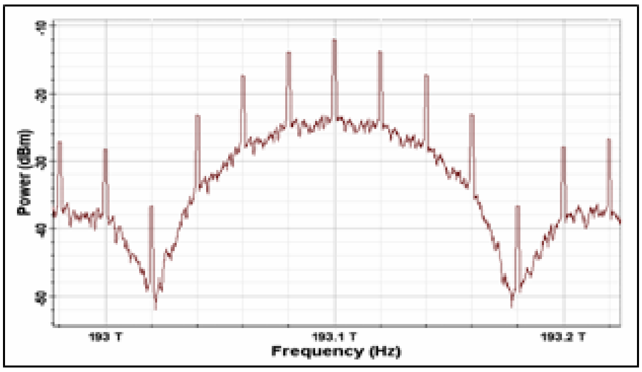
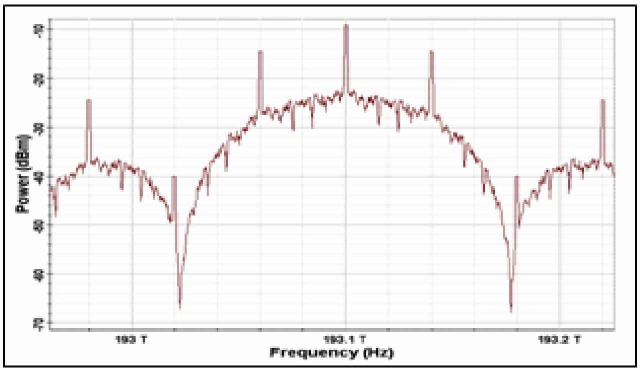


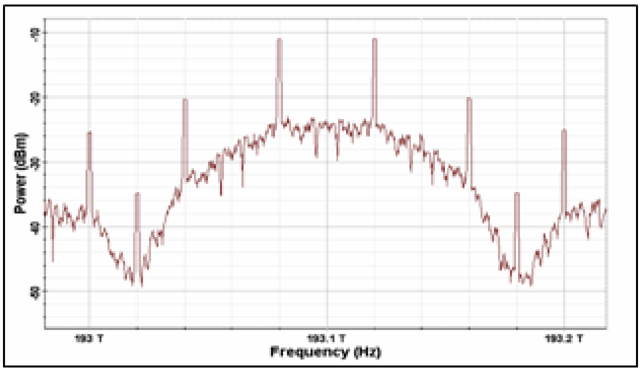
Figure 1 Generation of 40Gb/s PolSK signals.
PC: polarization controller, PBC: polarization beam combiner,
PBS: Polarization beam splitter, PM: Phase modulator



(a)



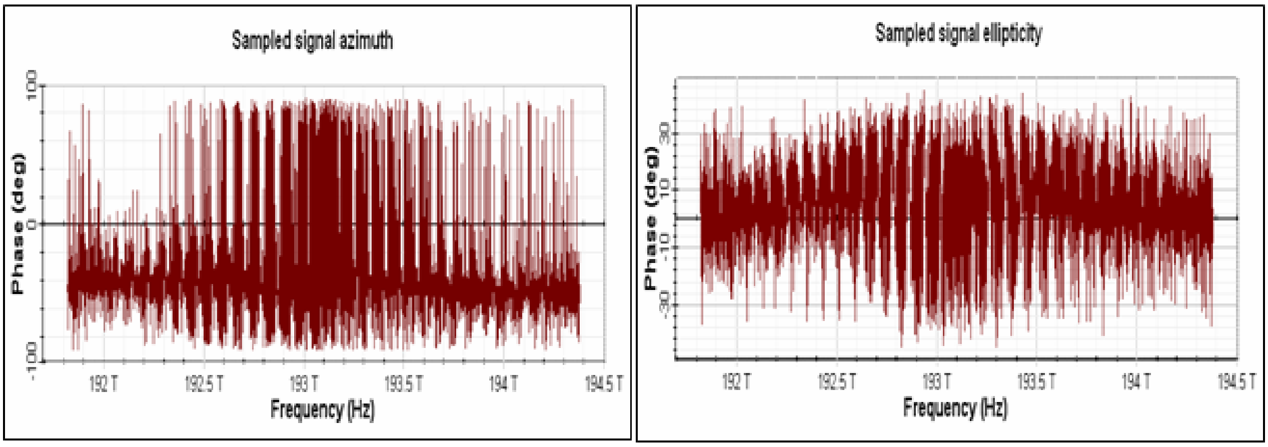
(b)



(c)

Figure 2 Spectrum of 40 Gb/s PolSK signal

1. spectrum at end of modulator
2. x- component spectrum
3. y-component spectrum



(a) (b)

Figure 3 Illustrate the polarization state versus frequency of optical signal at end of PolSK modulator. (a) Azimuth angle (b) Ellipticity angle

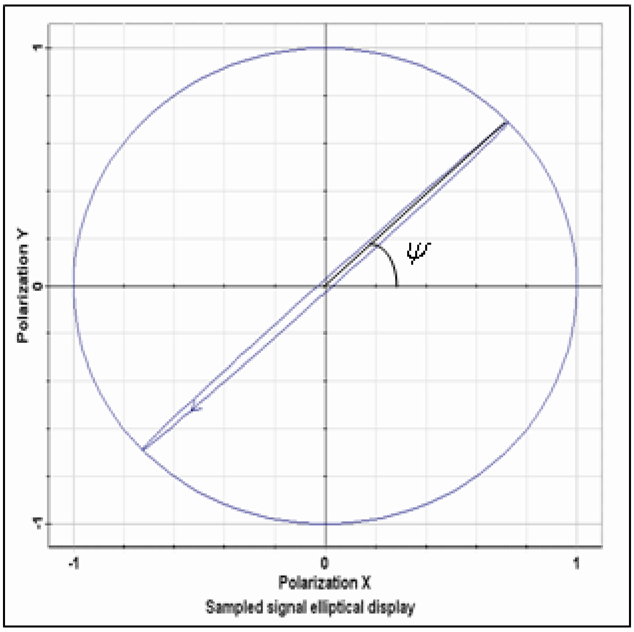


Figure 4 Elliptical display of signal polarization at end of PolSK

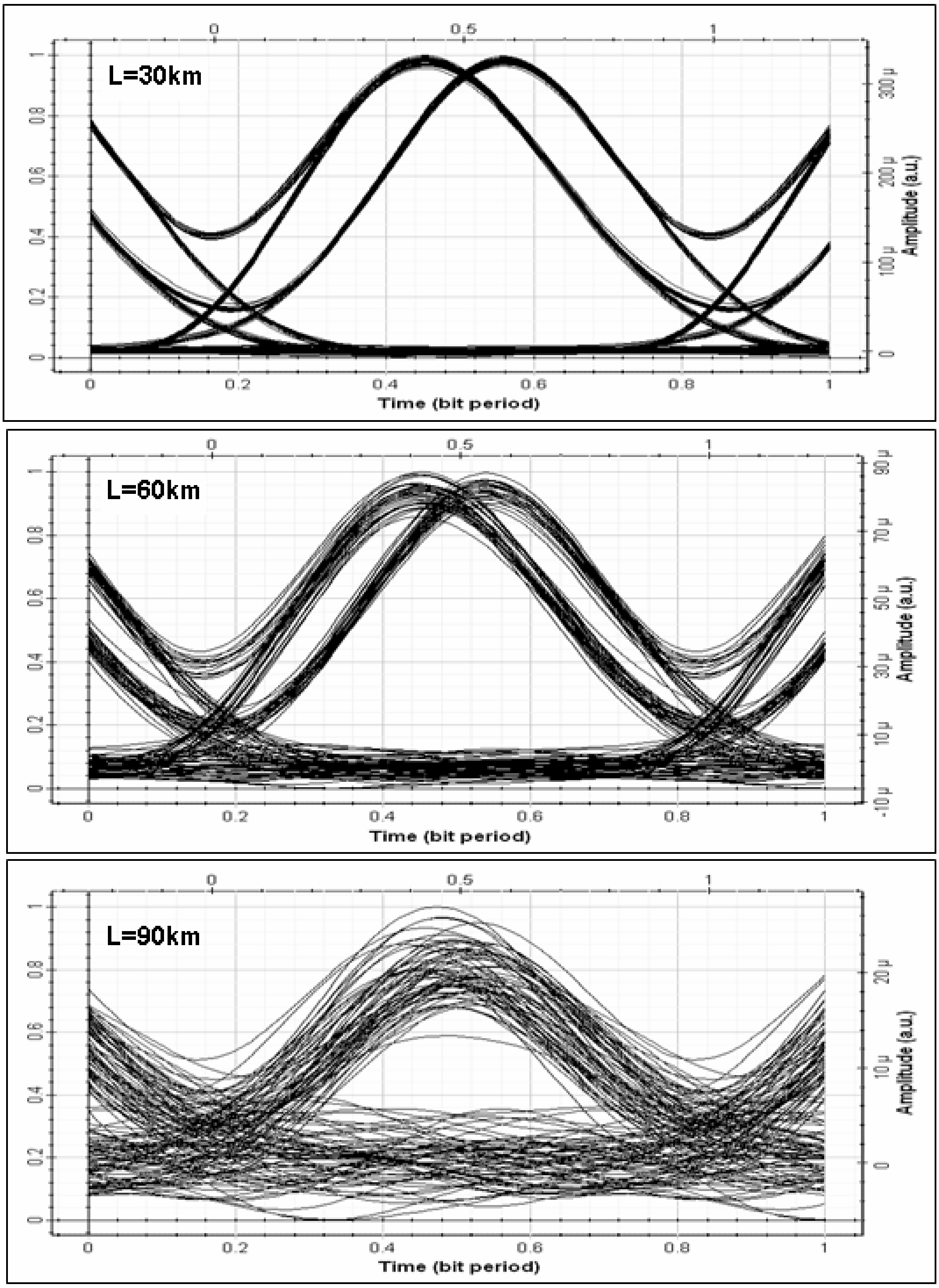


Figure 5 Eye diagram of received signal at various fiber length (L).