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Numerical Analysis of the DQPSK Modulation Formats Implementation With 40 Gbits/s

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Abstract

This paper treats the performances of an optical telecommunication system functioning with the 40 Gbit/s flow by a numerical analysis of the physical effects limiting the light guided propagation. The format studied here is a DQPSK modulation format (Differential Quaternary Keying Phase-Shift). It allows a transmission of information on four different levels of phase of the optical signals. Taking into account the complexity of the communication optical systems and joint action of many propagation physical effects (linear or non-linear), the optimization of the systems functioning with DQPSK modulation formats must be apprehended beforehand by digital simulations to direct the choices of the future designs. It is a study on a transmission with a single channel on only one optical fiber section. In particular, an analysis must be led concerning the impact on the transmission quality of the non-linear Kerr effects combined with the chromatic dispersion inherent of the propagation on optical fiber. The most effective technique to thwart the harmful impact of these effects is the management of chromatic dispersion. The obtained results will be presented and discussed.

Keywords: *Optical fiber, optical transmission systems, 40 Gbit/s flow, in phase modulation formats, OCEAN, numerical communications.*

1. Introduction

The use of optical fiber completely revolutionized the telecommunications world. One arrives from now on, at increasingly powerful transmission systems reaching several Tbit/s on several thousands of kilometers. Current research in this field aims at improving the systems performances multiplexed in wavelength Nx40 Gbit/s to even make them evolve to Nx100 Gbit/s systems [1].

Our objective relates on studies of the physical aspect of telecommunications optics of only one channel and to only one fiber section. This allowed us to estimate the performances of such a transmission system of which we are obliged to test it by a digital simulation.

2. Simulations Tool

As regards the guided propagation simulation of an optical signal, we use OCEAN software « Optical Communication Emulator for Alcatel Network». It is based on the iterative Split-Step Fourier Method SSFM.

The SSFM method principle consists of simulating the propagation of a visible signal on successive fiber portions where the dispersions effects and the nonlinear effects could be regarded as independent one of the other [2].

The SSFM method is an optimization method. The optical fiber is cut out in infinitesimal sections length dz. The length of these sections, defined according to the fiber Kerr, being.

Where:

$$L_{Kerr} = \frac{1}{P_{signal}.\gamma} \tag{1}$$

In the case of a transmission system of single channel, the step dz is taken equal to (1/100) the Kerr length.

3. Optical Fiber Digital Transmission System

The principal objective of a numerical system is to ensure the transmission without information error in the numerical form of a transmitter towards a receiver distant from a certain distance. We present on the Fig. 1 [3-5], the optical transmission systems diagram followed to carry out the digital simulations of the transmissions on only one fiber SSMF, while using the simulation program OCEAN [6]. The noted transmitter Tx generate a single channel, centered over the 1550 nm wavelength, modulated to 40 Gbit/s and modeled by a quaternary sequence of 1024 symbols. The modulation format used is DQPSK.

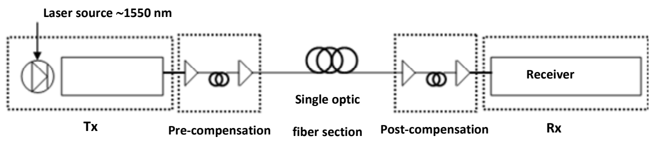


Fig. 1 General diagram of the digital simulations on only one optical fiber section

4. Differential Quaternary Phase-Shift Keying modulation format

The differential modulation in phase DQPSK for (Differential Quaternary Keying Phase-Shift) is a modulation format which comprises four different levels of phase. Moreover, the signal intensity coded in DQPSK remains constant in time, except on the level of the transitions from phase where reductions in intensity are observed in certain transmitter assemblies.

Each differential of phase codes on a group of two bits, sometimes called dibit or symbol, to choose among four: « 11 », « 10 », « 00 » ou « 01 ».

Fig. 2 recapitulates this attribution of debits according to the differential of phase and clarifies it by a representation on the trigonometrical circle.

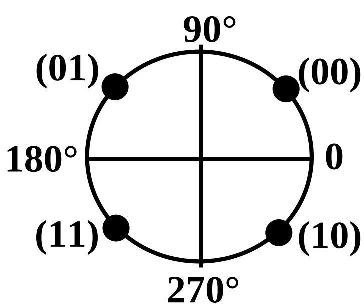


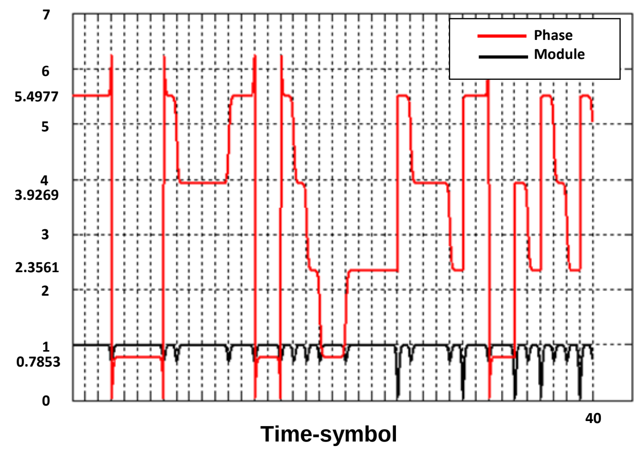
Fig. 2. Representation on the trigonometrical circle of attribution

4. Simulation results

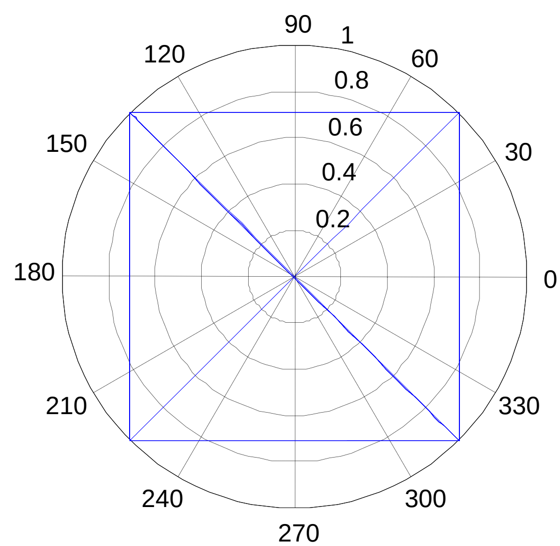
4.1. Linear physical effects results

Initially, we present the simulation results without transmission. For a numerical signal with 40 Gbit/s and optically modulated by the means of a modulation on four levels, the optical signal will transmit only 20 Gsymbols/s. Its modulation rate will be then 20 Gbaud, and its information frequency of 20 GHz.

The Fig. 3 illustrate an ideal case of a temporal evolution of a DQPSK signal with 40 Gbit/s for a number of symbols equal to 40 and each symbol lasts a time T equal to 46.49 ps.



(a)



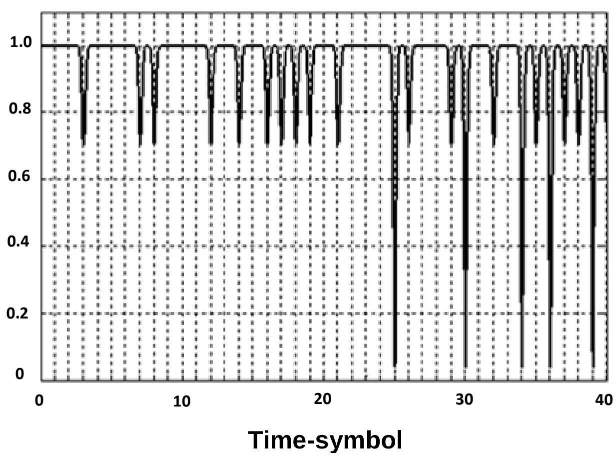
(b)

Fig. 3 (a) Temporal evolution of DQPSK signal with 40 Gbit/s
(b) Diagram in constellation of DQPSK signal with 40 Gbit/s

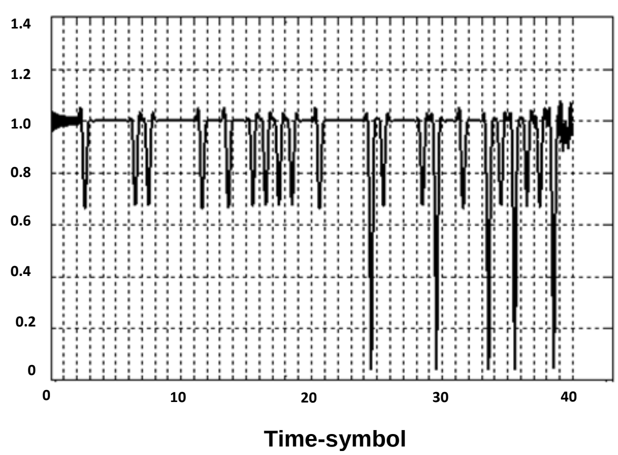
It is noticed that this signal is coded on four levels of phase and its amplitude is quasi constant. The return to zero, are carried out on the level of each transition from different phase is 0.7853 [rd] towards 3.9269 [rd] or 2.3561 [rd] towards 5.4977 [rd]. In the same way, one can trace this signal in the complexes plan (Fig. 3 (b)). In a more general way, one can locate each symbol in this diagram by its amplitude and its phase. This symbol takes four different states are « 00 », « 01 », « 10 », and « 11 » and each states can be associated a PRQS sequence symbol [7-8]. The simulated amplitude is standardized with a mathematical value of 1.

In the second part of simulations, we will introduce only the chromatic dispersion effect to our preceding optical signal. In the continuation of this paper, if nothing is specified, when the chromatic dispersion term is employed, it implicitly refers to cumulated dispersion.

The Fig. 4 illustrates the variation of the module of a temporal DQPSK signal evolution with 40 Gbit/s under the chromatic dispersion effect.



(a)

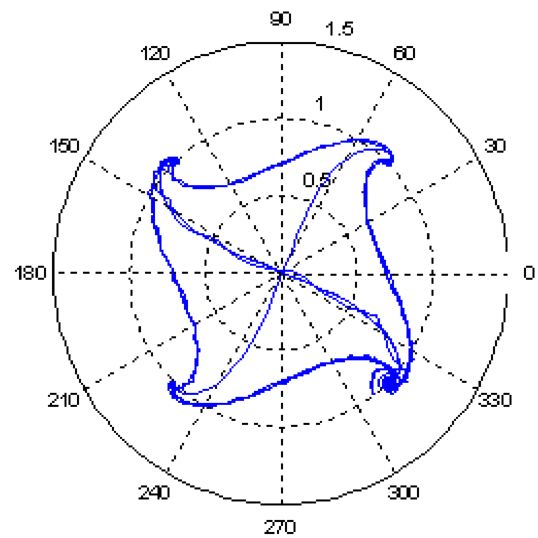


(b)

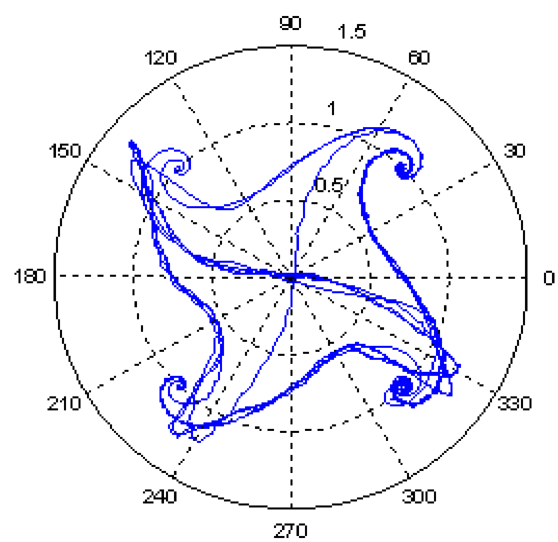
Fig. 4 (a) Module of a temporal DQPSK signal evolution without dispersion
(b) Module of a temporal DQPSK signal evolution with dispersion

One represents this temporal DQPSK signal evolution by the fact that a light wave modulated with a certain non null spectral width, has spectral components which are not propagated at the same speed. This generates a spectral dephasing which results in a temporal deformation from the optical signal.

One gathers this amplitude and phase variation in the introduction of the constellation illustrated by the Fig. 5. Indeed, it makes it possible to locate certain effects by their characteristic signature. This last show a chromatic dispersion equalizes with -32 ps/nm



(a)



(b)

Fig. 5 (a) Constellation transitions without dispertion of a DQPSK signal with 40 Gbits/s
(b) Constellation transitions with dispertion of a DQPSK signal with 40 Gbits/s

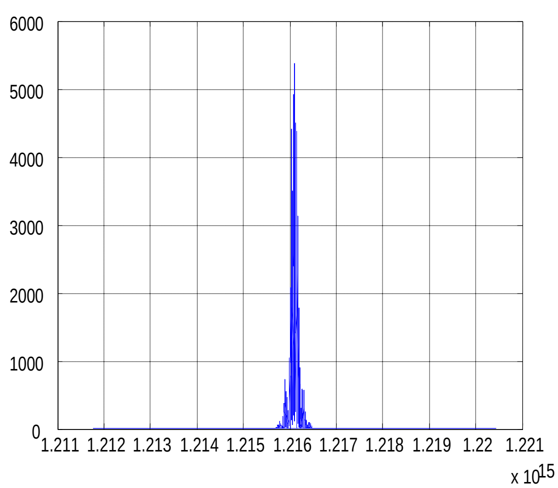
The physical interpretation of such a deformation of the constellation is shown in Fig. 5 by using a reasoning "time-frequency". Let us consider the spectral analysis of the sampled signal during its evolution between two transitions. The spectrum of this temporally truncated signal will have energy in the low frequencies, also truncated temporally but around a transition will have energy in higher frequencies. The phase variation due to the chromatic dispersion will be thus more significant for the transitions "rich" in high frequencies than for the symbols themselves what represents the phase rotation into spiral of the arms of transition from the constellation and stability in phase of the states.
The visual anomaly on the constellation of the Fig. 5 for the state located at a phase of 315° comes owing to the fact that for this constellation only 40 symbols are represented on the 1024 symbols of the complete signal.
The temporal variations of the optical signal characteristics consecutive to its modulation result in a certain width of its spectrum, in the spectral domain.

$$U(z,\omega)=U(z,0).\exp\left(\frac{i}{2}\beta_2\omega^2 z\right) \quad (2)$$

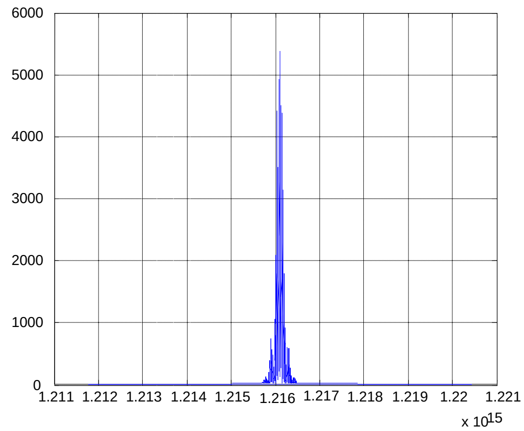
Whith :
β_2 is the dispersion the group speed given by the equation (3).

$$\beta_2=-\frac{\lambda^2}{2\ \pi\ c}D_{cum} \quad (3)$$

U(z,0) is the signal spectrum without chromatic dispersion
Fig. 6 shows the evolution of a modulated optical DQPSK signal versus frequency with 40 Gbit/s.



(a)



(b)

Fig. 6 (a) DQPSK signal evolution versus frequency
(b) Dispersed DQPSK signal evolution versus frequency

4.2. Non-linear physical effects results

In this section we present the non-linear physical effects results, in particular, the influence of the power on the propagation at the flow of 40 Gbit/s with DQPSK modulation (simulations with only one channel).
We previously saw that, more the channel power increases, more the non-linear effects appear. In particular, for transmissions with single channel without noise only the automodulation of phase (SPM, Self Phase Modulation) intervenes.
To characterize the non-linear effects accumulation, one can define two sizes which are as follows:
Integrated power P_{int}, equal to :

$$P_{\text{int}} = N_{\text{sections}}.\ P_{in} \quad (4)$$

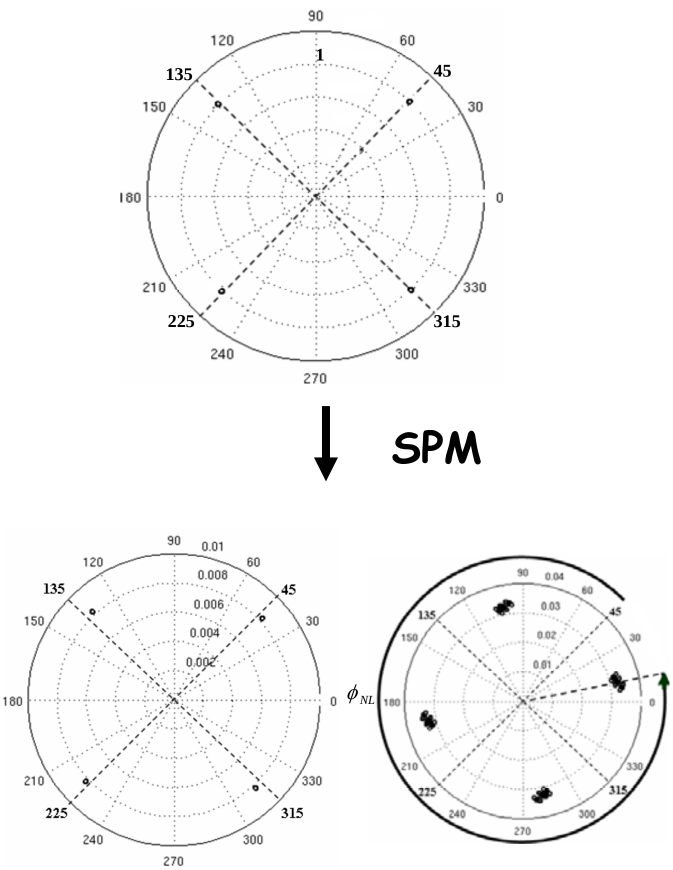
Where :
P_{in} is the input average power of the signal of a sigle channel, N_{sections} is the sections number of an optical transmission system.
Non-linear phase measured in radian [rd] : when the propagation takes place on only one fiber section, the dephasing formula corresponding to the non-linear phase can be simplified in:

$$\phi_{nl} = \gamma.P_{in}.L_{eff} \quad (5)$$

Where :
γ is the fiber non-linear coefficient [$w^{-1}km^{-1}$] that one finds in the equation of Schrödinger non-linear in fiber used,
P_{in} is the channel injected power into,
L_{eff} is the fiber effective length.

To illustrate the presence of Kerr effect, best is to use the constellation representation of an optical signal modulated on four levels of phase.

The Fig. 7 show two constellation examples without the transitions of a DQPSK modulation format (Differential Quaternary Keying Phase-Shift).



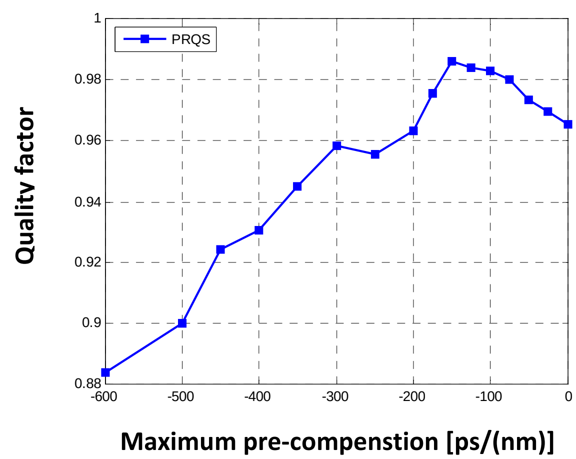
(a) **(b)**

Fig. 7. Effect of the SPM on a signal modulated in phase for:
(a) Dcum=4 ps/nm, precompmax=-75 ps/nm, and Pin=0 dBm
(b) Dcum=4 ps/nm, precompmax=-75 ps/nm, and Pin=12 dBm

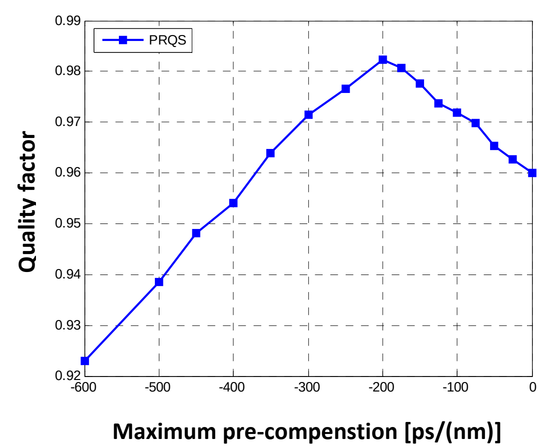
Values of phase initially taken of $(\frac{\pi}{4}, \frac{3\pi}{4}, \frac{5\pi}{4}, \frac{7\pi}{4})$ will evolve of a value equal to the non-linear phase ϕ_{NL}. When the injected input power in the optical transmission system, each of the four symbols is seen affected of an amplitude and phase fluctuation. Moreover the non-linear phase varies with the power. This effect degrades the information transport quality which will be able to prove penalizing for the optical signal propagation.

4.3. Influence of the Propagation Effects on the Quality Factor

We present here the simulation results and, in particular, the variation of the quality factor according to the maximum pre-compensation values. Let us take for example the case of transmission of a pseudo-random quaternary sequence [9-10] on a distance of 100 km of fiber with same chromatic dispersion as the Teralight fiber (Alcatel) (Fig. 8 (a)) and that of SMF (Fig. 8 (b)) for which the input power in the section is fixed at 4 dBm. One observes that there is a negative optimal pre-compensation value and, all the more strong in absolute value that the fiber dispersion is high.



(a)

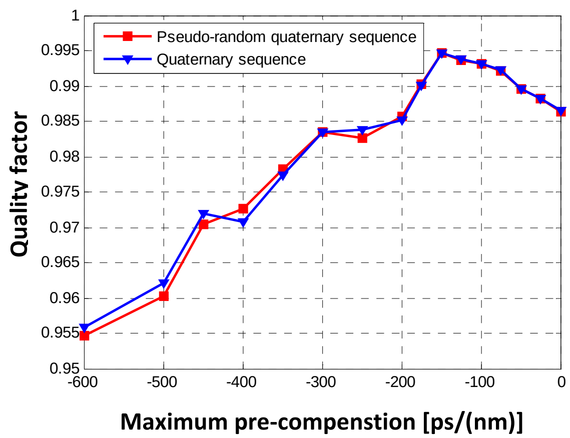


(b)

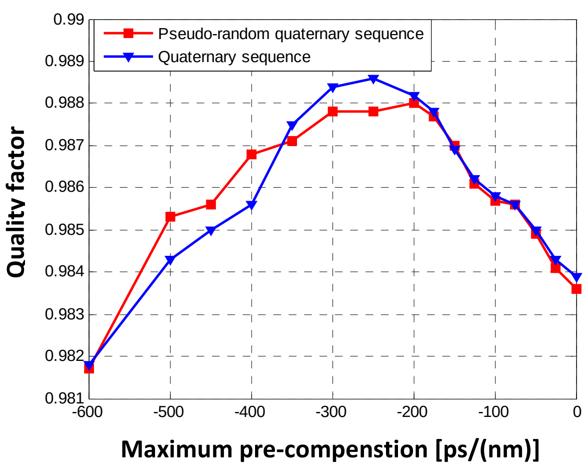
Fig. 8 The influence of the pre-compensation on the quality factor:
(a) Dcum=8 ps/nm, precompmax=-150 ps/nm, and Pin=4 dBm
(b) Dcum=16 ps/nm, precompmax=-200 ps/nm, and Pin=4 dBm

4.4. Comparison Between two Types of Sequences Partially Different in Term of Quality Factor

To evaluate the variation of the transmission quality according to the values of the pre-compensation, we will schematize two cases corresponding to the two types of sequences.



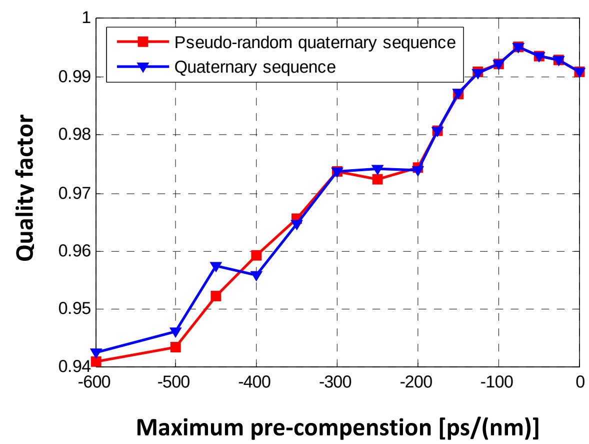
(a)



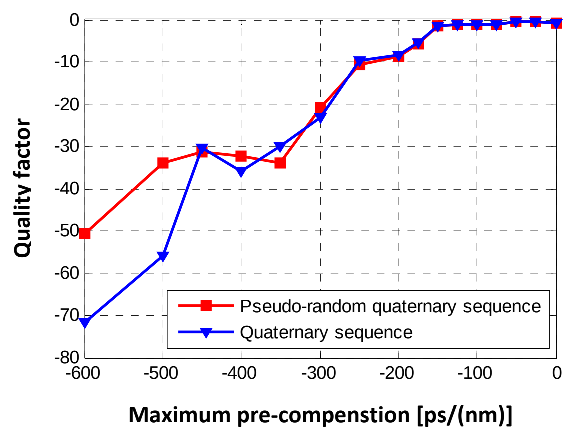
(b)

Fig. 9 Comparison between two types of sequences in term of quality factor :
(a) Dcum=8 ps/nm, precompmax=-150 ps/nm, and Pin=0 dBm
(b) Dcum=32 ps/nm, precompmax=-250 ps/nm, and Pin=0 dBm

Fig. 9 illustrates that there is not a great variation in term of quality factor between a pseudo-random quaternary sequence PRQS and another sequence which does not present all the properties that of a PRQS sequence but this variation is more significant when the local dispersion of fiber is strong and the pre-compensation lower than -200 ps/nm. As in session 4.3, one takes two examples of transmission on 100 km of Teralight fiber (Fig. 8 (a)) and of fiber having like characteristic a dispersion equal to 32 ps/(nm.km) to 1550 nm (Fig. 8 (b)). While fixing the input power equal to 0 dBm (1 mW on a linear scale), the maximum pre-compensation is always negative, larger in absolute value if dispersion is stronger. In our example, for dispersion equal to 32 ps/nm the maximum pre-compensation is of 250 ps/nm in absolute value which is larger only in the case of a Teralight fiber (Fig. 8 (a)). In the first case, that which is showed in Fig. 9 (a), notices that the quality factor equal to 0.995, is as good as that of Fig. 9 (b).
In the continuation, one focuses in the same reasoning but this time, one is interested in the results allowing to give a vision on the influence of the power on the quality factor.



(a)



(b)

Fig. 10 Comparison between two types of sequences in term of quality factor
(a) Dcum=4 ps/nm, precompmax=-75 ps/nm, and Pin=0 dBm
(b) Dcum=4 ps/nm, precompmax=-50 ps/nm, and Pin=20 dBm

Fig. 10 (a) shows that the quality factor of a fiber known as (Broad Effective Area Fiber) is equal to 0.9952 when the power is 1 mW. In the worse case i.e. for a power equalizes to 20 dBm, one notice that the values of the quality factor take negative values, note that it has a value of -0.3369 for a maximum pre-compensation equalizes with -50 ps/nm.

4.4. Treatment on the Maximum Pre-compensation

The chromatic dispersion management utilizes unfortunately a great number of parameters and the joint influence of dispersion and the non-linear effects make its optimization vast and complex. Fig. 11 shows the influence of chromatic dispersion on the maximum pre-compensation for various values of power going from 0 dBm to 20 dBm. Notices indeed that for a fiber having a cumulated dispersion to 4 ps/nm equalizes, the maximum pre-compensation is of -75 ps/nm and remains identical for various values of power except in the case of a power of 20 dBm.

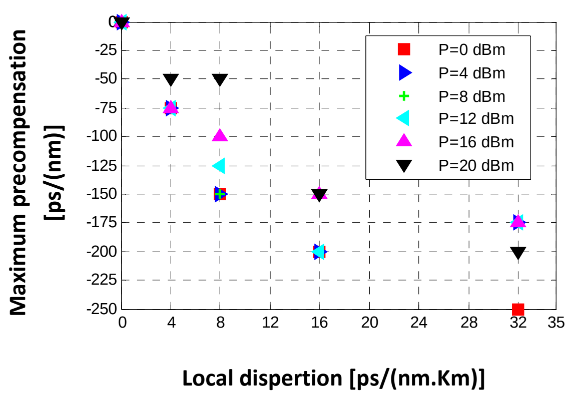


Fig. 11 Influence local dispersion of fiber on the maximum pre-compensation

5. Conclusions

In this paper, we carried out a simulation of transmission at 40 Gbit/s by channel, which proves now imminent for the terrestrial systems. The numerical analysis of the propagation effects taught us that the introduction of the nonlinear effects of Kerr type particularly by the SPM implies a rotation of the phase proportional to the power of the signal, and that chromatic dispersion results in a fluctuation of phase to each transition. During all the carried out studies, the chromatic dispersion management presents the heart of the found results. This technique enabled us to control not only the non-linear dispersion but also effects. To ensure an optimal transmission within a transmission system, it is well necessary to adjust several parameters such as chromatic dispersion, the input power and the compensation along the system.

Acknowledgments

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