Available online **www.jsaer.com**

***Journal of Scientific and Engineering Research*, 2021, 8(8):158-165**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Modal Polarization Modal Dispersion Effects in a Fiber Optic Telecommunication Network in the City of Kinshasa

Mumay Muluba John, Lidinga Mobonda Flory, Alfred Raoul MISSETETE, Rodrigue Armel Patrick Okemba, Gomba Rodolphe

*Laboratoire de Génie Electrique et Electronique, Ecole Nationale Supérieure Polytechnique, Université Marien Ngouabi, Brazzaville, Congo

Abstract In this article, we model the polarization modal effects in a telecommunication network in the city of Kinshasa using fiber optic technology. The various mathematical methods making it possible to determine the dynamic behavior of the polarization modal dispersions and to model the parameters of the data transmission rate and distance in the local network. The developed equations address the problem of frequency loss. The objective of this article is to model the dispersion modal chromatic polarizations, as well as their impacts in a very high speed link, that is to say a FTTH (fiber to the home) link. These phenomena being physical, we will model them and simulate their results, finally, analyze their impact in a fiber optic information transmission link.

Keywords Effect modeling, Modal polarization dispersions, Telecommunication network, Optical fiber

1. Introduction

To fully understand the effects of the polarization modal dispersion in the optical fiber, we must go through the modeling of these. Two effects contribute to the total chromatic dispersion in the fiber. These are the dispersion due to the material (glass) and the dispersion due to the waveguide (fiber), which depends on the index profile of the fiber. In single-mode fibers with an asymmetric profile of revolution, chromatic dispersion is the main cause of the widening of the pulses. This distortion can make information unreadable.

2. Mathematical Description of the Modal Dispersion of Polarization

The coupling of several pieces of fiber for the transmission of a signal at a certain distance L, injected at the entrance of the fiber will undergo degeneration and will propagate inside the fiber on two slow and fast axes. Several optical fibers being put in concatenation can cause the mode coupling which is the consequence of the weakness of the birefringence in the single-mode fibers. Because of this weakness, the two polarization modes can easily couple and exchange energy [1].

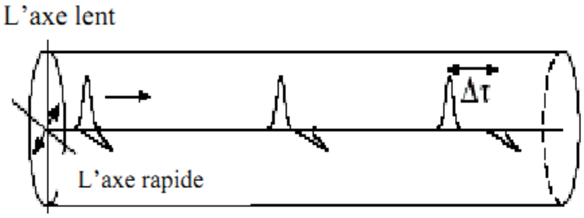

Figure 1: The division of a pulse moving along a fiber

The PMD of an optical fiber is totally determined by the mean value τ of the group time difference. The group differential delay time (DGD), denoted by τ will be the quadratic sum Δτ2. If we consider the different sections of the fibers in concatenation of length L, we can calculate the root mean square by the relation [2].

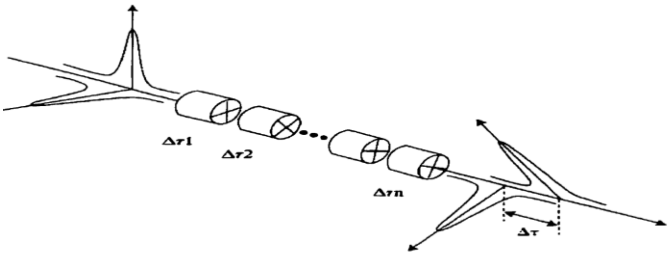

Figure 2: Representation of a long fiber as a series of randomly concatenated bire fringent elements

Considering, the different group delay times in each concatenated section ΔT1; ΔT2; ΔTn and by setting ΔT = Δτ, one can calculate the quadratic mean. It is given by the relation:

$$< \Delta\tau_{tot} >^2 = < \Delta\tau_1 >^2 + < \Delta\tau_2 >^2 + \cdots + < \Delta\tau_n >^2 \qquad (2.1)$$

$$< \Delta\tau_{tot} > = \sqrt{< \Delta\tau_1 >^2 + < \Delta\tau_2 >^2 + \cdots + < \Delta\tau_n >^2} \qquad (2.2)$$

where Δτn is an average differential group delay contribution of element n. In the case of a cascade of short, deterministic, randomly oriented PMD components, the average differential group delay contribution <Δτn> is replaced by Δτn of each element. At a given instant and for a given wavelength, the differential group delay Δτtot follows a Maxwellian probability density function [3].

$$f(\Delta\tau_{tot}) = \sqrt{\frac{2}{\pi}\frac{(\Delta\tau_{tot})^2}{(\alpha)^2} exp\left[\frac{(\Delta\tau_{tot})^2}{2(\alpha)^2}\right]} \qquad (2.3)$$

Whit:

$$\alpha = \frac{1}{<\Delta\tau_{tot}>}\sqrt{\frac{\pi}{8}} \qquad (2.4)$$

In the case of long fiber links, the total link Llien is divided into n segments of length ln with identical mean differential delay

We can calculate the root mean square value of n segment, knowing the number of segments of the length of the link and the differential delay.

The root mean square value is given by the square root of link number n multiplied by the group differential delay. This value is expressed by [5]:

$$< \Delta\tau_{tot} > = n^{\frac{1}{2}} < \tau_{n>} \qquad (2.5)$$

We can determine the value of n, from the total length L of the fiber and the length of the link. $l_n n = {}^{L}/_{< l_{n>}}$, by replacing this value, we have:

$$\Delta\tau_{tot} = L^{\frac{1}{2}}\frac{<\Delta\tau_n>}{<l_n>^{\frac{1}{2}}} \qquad (2.6)$$

The term $\frac{<\Delta\tau_n>}{<l_n>^{\frac{1}{2}}}$ is the coefficient of PMD normalized per unit square root of length. The relation can be defined according to the modal dispersion and the square root of the fiber, as given by the relation below.

$$\Delta\tau_{tot} = L^{\frac{1}{2}}\frac{<\Delta\tau_n>}{<l_n>^{\frac{1}{2}}} = L^{\frac{1}{2}}PMD = \sqrt{L}PMD \qquad (2.7)$$

Ultimately, this relation gives the value of the group differential delay time as a function of two line parameters which are the PMD and the total length of the fiber. We can derive the value of the PMD:

$$PMD = \frac{\tau_{max}}{\sqrt{L}} \qquad (2.8)$$

Since PMD is a dispersion which contributes to the degradation of the signal in the optical fiber, its certain compensation by processes is essential.

2.1. PMD Compensators

To compensate for PMD in an optical network, several methods are used, namely:

the mechanical system: reduce a section of the optical fiber to realign the polarization of the optical pulses for each bit; the electronic system:

manipulating electrons to reduce bit error rates;

adaptation of the optical system: realign and correct the pulses of the scattered bits.

2.2. Measurement of PMD

PMD can affect the different stages of the deployment of a fiber network and must be measured:

during the manufacture of the optical fiber (factory);

during the manufacture of the cable (factory);

After installing the cable dedicated to very high speed transmission (field) 10 Gbits / s per channel or higher;

When planning the expansion of an existing network (field), fibers manufactured before 1995 must be verified;

Regularly check the optical fiber throughout the life of the network (environmental conditions).

In view of the above, the presence of these two dispersions, namely chromatic and modal polarization, can be simultaneous. This fact prompted us to conduct the studies in order to model them, examine their effects and interpret the results.

2.3. Transmission techniques

Optical fibers have, in the spectral window generally used, a very large usable band (about 15 THz around the 1.55 µm wavelength). Theoretically, the bit rates which can be transmitted are therefore extremely high. This is all the more interesting now that the number and size of information exchanged is more and more important. However, at present, the electronic processing of electrical signals before modulation and after detection does not reach such frequencies. This is why various solutions have been devised to take advantage of the capabilities of optical fiber and therefore increase the transfer of information on the same channel. In most cases, the principle remains the same: use N signals at rate Equivalent in terms of capacity to one signal at N * D rate, which is currently impractical. This is called multiplexing, and the speeds transported would now be higher. The concentrated signal of the streams of various origins is called the multiplex signal. To maintain the integrity of each signal on the channel, multiplexing introduces a temporal, spatial or frequency separation between the signals [4].

2.3.1. Time-division multiplexing (TDM)

TDM (Time Division Multiplexing) consists of allocating all of the bandwidth to a single user for a short time, in turn for each user. The allocation of this bandwidth is done by dividing the time axis into periods of fixed duration, and each user will only transmit during one of these determined periods. A fixed time interval (IT) is successively assigned to a source. TDM multiplexing then makes it possible to combine several low-speed communications channels onto a single higher-speed channel (for example, design of a 40 Gbits / s speed, from 4 sequences at 10 Gbits / s).

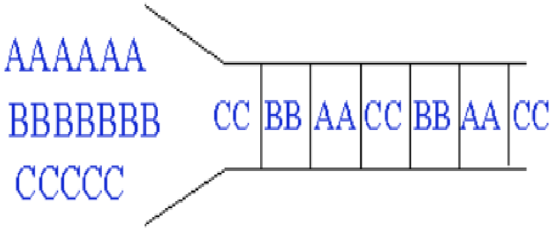

Figure 3: Distribution of periods in the case of TDM multiplexing.

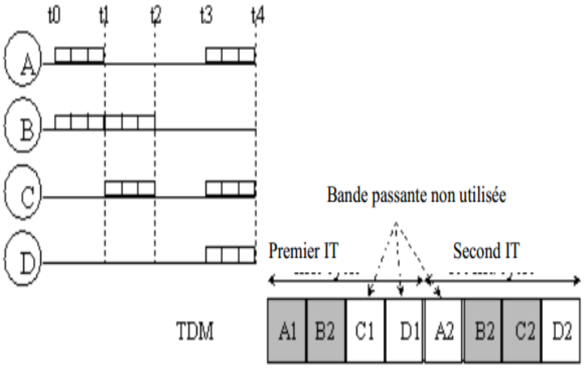

Figure 4: Representation of a TDM multiplex (4 channels to 1) according to the initial data.

2.3.2. Optical (OTDM)

Time division multiplexing can be carried out optically (OTDM, Optical Time Division Multiplexing). The transmitter consists of N optical sources in parallel modulated at the rate Db bits / s. This technique requires that the optical signals are then RZ-type coded so that the coded pulses now have a duration of less than Tb / N and that the optical multiplexing can be done without optical overlap [1].

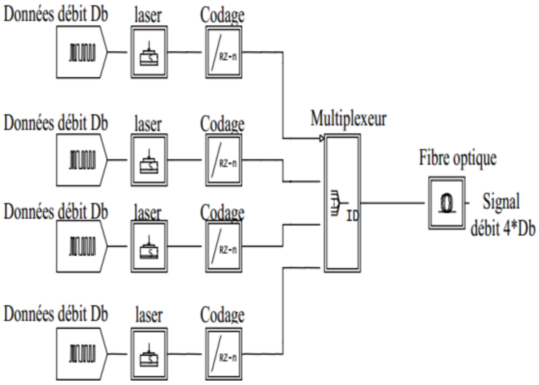

Figure 5: Block diagram of OTDM multiplexing

2.3.3. Limitation of PMD in the transmission system

The statistical nature of the PMD is taken into account by the fact that, to determine the maximum authorized PMD delay, only one tenth of the width of the TB bit is authorized, that is to say , $\tau_{max} \leq \frac{T_b}{10}$.

The International Telecommunications Union has standardized the various fibers according to PMD.

The International Telecommunications Union has standardized the various fibers according to PMD.

The limitation of the PMD will be demonstrated by the data of the following PMD values respectively: 2ps/ $\sqrt{km}$, 0.2ps/$\sqrt{km}$ et 0.05 /$\sqrt{km}$. The different standard flow rates are: 2.5 Gbit/s; 10 Gbit/s; 40 Gbit/s et 160 Gbit/s. If we consider that this phenomenon becomes annoying from 10% of the bit time, a PMD of 10 ps (resp. 2.5 ps) is the tolerable limit for a flow of 10 Gbit / s (resp. 40 Gbit / s). With all this data, we can determine the scope of the link, knowing that the value τmax must be less than or equal to 10%-bit time.

$\tau_{max} \leq \frac{T_b}{10}$,$\tau_{max} = 0.1\, T_b$,

$$B = \frac{1}{T_b} \qquad (2.9)$$

The bit rate will be given by the relation as a function of the PMD and the length of the fiber will be given by the relation.

$$B = \frac{1}{10\; PMD.\sqrt{L}} \qquad (2.10)$$

This relationship makes it possible to simulate the change in flow rate as a function of length for different types of fibers characterized by their polarization modal dispersion, PMD.

2.4. Network configuration under study

2.4.1. Local network

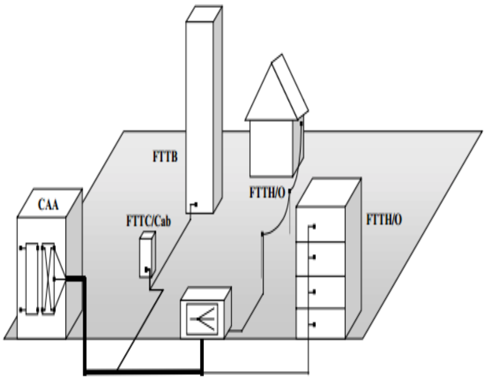

Figure 6: The local network.

2.4.2. Electronics (ETDM)

OTDM has its equivalent in electronics, ETDM (Electronic Time Division Multiplexing). In the case of ETDM, the RZ encoding and "stitching" of the data is done electrically [6].

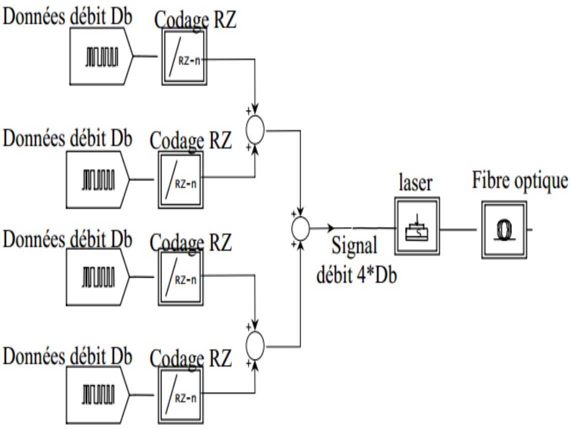

Figure 7: Block diagram of ETDM multiplexing

The high speed obtained is then used for the modulation of the bias current of a laser diode and there is only one light signal emitted. This step is shown schematically in Figure II.9 by the presence of three electronic circuits and an electronic multiplexer (fast circuit) [2].

2.4.3. Time multiplexing on T1 channels We find this type of time division.

Multiplexing on the channels T1 or E1 can be multiplexed together to form channels at higher bit rates (Figure II.10). This throughput hierarchy is called the plesiochronous digital hierarchy or PDH (Plesiochronous Digital Hierarchy).

3. Results & Discussion

In this part, we present simulation of the different scopes from relationships below.

$$\tau_{max} = PMD.\sqrt{L} \tag{3.1}$$

$$B = \frac{1}{10PMD.\sqrt{L}} \tag{3.2}$$

For a fixed flow, with different PMD values, we calculated the different capacities using the formula:

$$l = \frac{(\tau_{max})^2}{(PMD)^2} \tag{3.3}$$

3.1. Throughput value equal to 2.5 Gbit/s

Considering a throughput value equal to 2.5 Gbit / s, with the values of PMD respectively: 0.05ps/$\sqrt{km}$; 0.2ps/$\sqrt{km}$; 2ps/$\sqrt{km}$, we calculated and simulated the different spans.

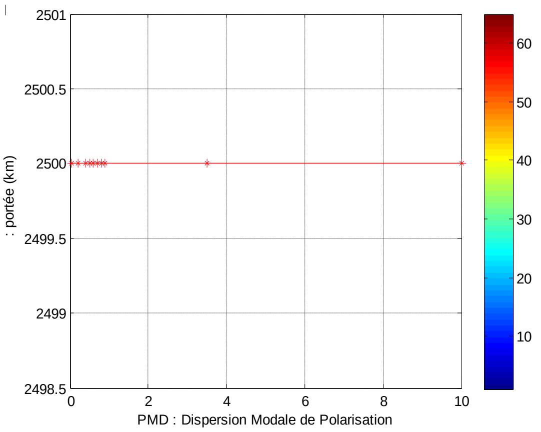

Figure 8: Simulation V of throughput equal to 2.5 Gbit /s.

3.2. Throughput equal to 10 Gbit /s.

Considering a throughput value equal to 10 Gbit / s, with the values of PMD respectively: 0.05ps/$\sqrt{km}$; 0.2ps/$\sqrt{km}$; 2ps/$\sqrt{km}$, we calculated and simulated the different spans.

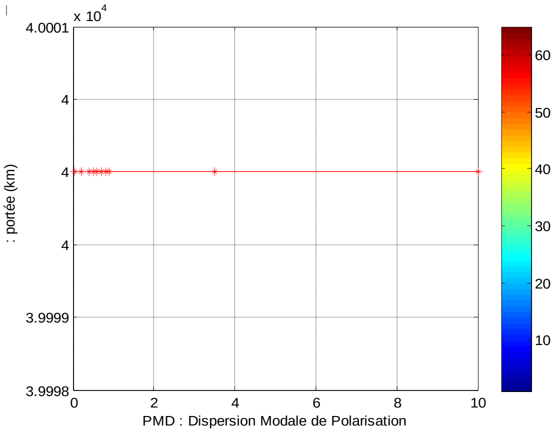

Figure 9: Simulation V of throughput equal to 10 Gbit /s.

3.3. Throughput value equal to 40 Gbit/s

Considering a throughput value equal to 40 Gbit / s, with the values of PMD respectively: 0.05ps/$\sqrt{km}$; 0.2ps/$\sqrt{km}$; 2ps/$\sqrt{km}$, we calculated and simulated the different spans.

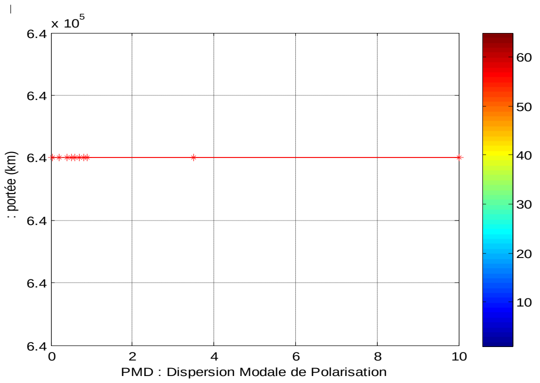

Figure 10: Simulation V of throughput equal to 40 Gbit /s.

3.4. Throughput value equal to 160 Gbit/s

Considering a throughput value equal to 160 Gbit / s, with the values of PMD respectively: 0.05ps/$\sqrt{km}$; 0.2ps/$\sqrt{km}$; 2ps/$\sqrt{km}$, we calculated and simulated the different spans.

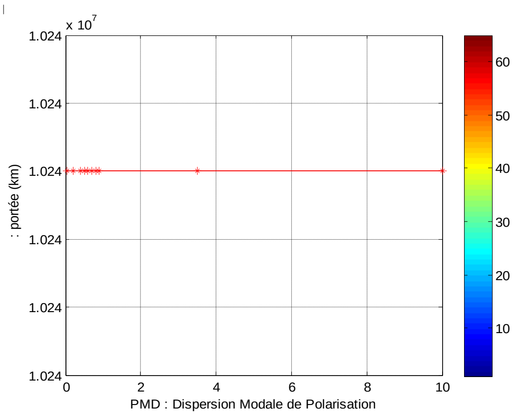

Figure 10: Simulation V of throughput equal to 160 Gbit /s.

4. Conclusion

We have seen that this article consisted in modeling the effects of polarization modal dispersion (PMD) in the fiber optic telecommunications network. Systematic analysis of the effects of dispersion shows that polarization modal dispersion is the parameter that limits transmission:

increasing the flow rate by a factor of 4 reduces the distance by a factor of 10. The poor quality of the optical fiber can make the fiber inoperable during the migration to very high speed. The countries which are in the process of building their long-distance optical fiber infrastructure (national backbone), must take these parameters into account in PMD. This is the case with African countries in general which are fully migrating to very high speed broadband and in particular the Democratic Republic of Congo (DRC) which is in the process of building its national backbone with a length of 1300km. Having understood that PMD has an impact on the transmission of data in an optical network, we can talk about how one can handle optical fibers with high values of PMD.

References

[1]. Maxim Integrated Products (2002). Optical Signal-to-Noise Ratio and the Q-Factor in Fiber-Optic Communication Systems. MAXIM High-Frequency/Fiber Communications Group.

[2]. Dubois, A. (2001). Simulation de systèmes de télécommunications par fibre optique: de la conception des systèmes à la validation des composants. Thèse en Télécommunications Hautes Fréquences et Optique, Université de Limoges.

[3]. Morishita K. (1981). Numerical analysis of pulse broadening in graded index optical fibers. IEEE Transactions on Microwave and Technique, vol. 29, n° 4, p348-352.

[4]. Shenoy M.R., Thyagarajan K., Ghatak K. (1988). Numerical analysis of optical fibers using matrix approach. Journal of Light wave Technology, vol. 6, n° 8, p1285-1290.

[5]. Marcou J., Auguste J.l., & Blondy J.M. (1999). Cylindrical 2D beam propagation method for optical structure maintaining a revolutionary symmetry. Optical Fiber Technology, vol. 5, p105-118.

[6]. Boucouvalas, A.C. (1985). Coaxial optical fiber coupling. Journal of Light wave Technology, vol. 3, n° 5, p1151-1158.

Biography

MUMAY MULUBA John,
Telecommunications engineer ISTA-KIN in D.R of Congo.
Research Master in 2012 ESP-University Cheikh Anta Diop Dakar
Doctor student of University national pedagogy of Kinshasa-Congo. of Applied Sciences

Prof. Dr. Ir **Lidinga Mobonda Flory**,
PhD In Engineering Sciences.
Electrical and Elctronic Engineering Research Laboratory ENSP-UMNG
National President of the National Network of Engineers of the DR Congo

Alfred Raoul MISSETETE, PhD Engineering Sciences.
He is presently lecturer at the University of Brazzaville-Congo, Dept. of Mechanics and electricity.
Engineering Research Laboratory ENSP-UMNG

Rodrigue Armel Patrick Okemba
PhD in engineering sciences of The University of Brazzaville-Congo.
Electrical and Elctronic Engineering Research Laboratory ENSP-UMNG

Dr. Ir **Gomba Rodolphe**,
PhD In Engineering Sciences,
Dept. Of Electricity.
Electrical and Elctronic Engineering Research Laboratory ENSP-UMNG
network.Director-General of the National Rural Electrification Agency (ANER).