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MODELING OF CHROMATIC DISPERSION EFFECTS IN A FIBER OPTIC INFORMATION TRANSMISSION NETWORK IN THE CITY OF KINSHASA.

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ABSTRACT

In this article, we model the chromatic effects in the information transmission network of the city of Kinshasa using fiber optic technology. The different mathematical methods used to determine the dynamic behavior of chromatic dispersions and to model the parameters of signal losses. The developed equations address the issue of data transmission in the local network of an academic establishment.

The objective of this article is to model the chromatic dispersion, as well as their impacts in a very high speed link, that is to say with the technology of optical fiber up to the office. These phenomena being physical, we will model them and simulate their results, finally, analyze their impact in a fiber optic information transmission link.

Keywords: Effects modeling, Chromatic dispersion, Transmission network, Information, Optical fiber.

1. INTRODUCTION

To fully understand the effects of chromatic 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 pulse broadening. This distortion can make information unreadable.

1.1 Equation of Chromatic Dispersion

1.1.1 Mathematical concepts

According to the group index, N is given by the formula:

$$N = \frac{C}{V_g} \qquad (1.1)$$

Relation (1.1) defines the index of group N as a function of the speed of light c and the group speed Vg. The effective index can be given as a function of the propagation constant and the wave vector. Let ne be the effective index of this mode at the given wavelength:

$$n_e = \frac{\beta}{k_0} \qquad (1.2)$$

By integrating the definition provided, the refractive index of group N can be expressed by the following relation:

$$N = n_e + k_0 \frac{d\, n_e}{d\, k_0} \qquad (1.3)$$

Group time therefore becomes:

$$t_g = \frac{L}{V_g} = \frac{L}{C} \frac{d\,\beta}{d\left(\frac{2\pi}{\lambda}\right)} = \frac{L\lambda^2 d\,\beta}{2\pi C 2 d\lambda} \qquad (1.4)$$

The temporal lengthening τ is defined by:

$$\tau = \frac{dt_g \Delta\lambda}{d\lambda} \qquad (1.5)$$

With Δλ, the spectral width of the pulse. From the chromatic dispersion Dch can then be defined by:

$$D_{ch} = \frac{\tau}{L\Delta\lambda} = \frac{1}{L} \frac{d\, t_g}{L\, d\lambda} = -\frac{2\pi L}{\lambda^2} \beta_0'' \qquad (1.6)$$

As a first approximation and neglecting the cross contribution of the two first derivatives with respect to the refractive index n and the frequency v, thechromatic dispersion appears, as the sum of the dispersion of the material (Dmat) and the dispersion of the guide (D guide). According to the same authors, it is then expressed by the following relation:

$$D_{ch} = D_{mat} + D_{guide} \qquad (1.7)$$

1.1.2 Material dispersion

The propagation constant of a mode in a fiber is given by the relation:

$$\beta = k_0 n_e \qquad (1.8)$$

Since the mode is mainly confined in the core of the fiber with a refractive index n1 close to ne, we will assume that:

Avec $n_2 < n_e < n_1$

$$\beta(\lambda) = k_0 n_1 \quad (c) \qquad (1.9)$$

The wave transit time to travel a distance L can be given by:

$$t_{mat} = \frac{L}{V_g} = L \frac{d\beta}{d\lambda} \frac{d\lambda}{d\omega} \qquad (1.10)$$

With:

$$\frac{d\beta}{d\lambda} = -\frac{2\pi}{\lambda^2} n_1 + \frac{2\pi}{\lambda} \frac{dn_1}{d\lambda} \qquad (1.11)$$

By replacing relation (2.10) in (2.9), equation (2.10) can therefore be written :

$$\tau_{mat} = L\left(-\frac{2\pi}{\lambda^2}n_1 + \frac{2\pi}{\lambda}\frac{dn_1}{d\lambda}\right)\left(\frac{2\pi C}{\omega^2}\right) \quad (1.12)$$

$$\tau_{mat} = L\left(-\frac{2\pi}{\lambda^2}n_1 + \frac{2\pi}{\lambda}\frac{dn_1}{d\lambda}\right) \quad (1.13)$$

$$\tau_{mat} = \frac{L}{C}\left(n_1 - \lambda\frac{dn_1}{d\lambda}\right) \quad (1.14)$$

Thus the temporal lengthening of the impulse (or impulse spreading) is defined by the following relation:

$$\tau_{mat} = \frac{d\tau_{mat}}{d\lambda}\Delta\lambda \quad (1.15)$$

By replacing relation (1.14) in relation (1.15), we obtain the following relation (1.16):

$$\tau_{mat} = \frac{L}{C}\left(\frac{dn_1}{d\lambda} - \frac{dn_1}{d\lambda} - \lambda\frac{d^2n_1}{d\lambda^2}\right)\Delta\lambda \quad (1.16)$$

The calculation of this relation (1.16), gives the following result:

$$\tau_{mat} = \frac{L}{C}\lambda\frac{d^2n_1}{d\lambda^2}\Delta\lambda \quad (2.17)$$

Now the dispersion of the material is defined such that.

$$D_{mat} = \frac{\tau_{mat}}{L\Delta\lambda} \quad (1.18)$$

From where

$$D_{mat} = \frac{L}{C}\frac{d^2n_1}{d\lambda^2} \quad (1.19)$$

From all of the above, it should be pointed out that silica is among the materials that are used in the manufacture of optical fiber. It has increasing wavelengths in the near infrared region with negative dispersion, this is normal dispersion, and zero dispersion for λ is equal to 1310 nm. This value can also be positive, which can correspond to the abnormal dispersion.

1.1.3 Guide dispersion

The transit time tg for the dispersion of the guide is written in the form:

$$t_g = \frac{L}{C}\frac{d\beta}{d\omega} \quad (1.20)$$

This eliminates the dependence of the refractive index of the material on the wavelength. The normalized spatial frequency V is defined by:

$$V^2 = = U^{2+} W^2 \quad (1.21)$$

where U and We are respectively normalized transverse propagation constants in the core and the cladding:

$$U = a(n^2{}_1k^2{}_0 - \beta^2)^{1/2} \quad (1.22)$$

$$W = a(\beta^2 - n^2{}_2k^2{}_0)^{1/2} \quad (1.23)$$

Let b be the normalized propagation constant, we have:

$$b = 1 - \frac{U^2}{V^2} \simeq \frac{\frac{\beta}{k_0} - n_2}{n_1 - n_2} \quad (1.24)$$

We can therefore make an approximation of β therefore, the transit time can be calculated from this relation:

$$t_g = \frac{L}{C}\frac{d\,\beta}{d\,\omega} = \frac{L}{C}\frac{d\,[\,k_0(n_2 + \,b\,n_1\Delta)]}{d\,k_0} \quad (1.25)$$

$$t_g = \frac{L}{C}\left[n_2 + n_1\,\Delta\,\frac{d\,(bk_0)}{dk_0}\right] \quad (1.26)$$

We can derive the value from dk0 and will be given by the relation:

$$dk_0 = \frac{dV}{a\,n_{1.\sqrt{2\Delta}}} = \frac{d\,V}{A} \quad (1.27)$$

By replacing relation (1.27) in (1.26), we obtain:

$$t_g = \frac{L}{C}\left[n_2 + n_1\Delta\frac{d[V.b]}{d\left(\frac{V}{A}\right)}\right] = \frac{L}{c}\left[n_2 + n_1\Delta\frac{d(Vb)}{d(V)}\right] \quad (1.28)$$

The spread of the pulse τg is defined by:

$$\tau_g = \frac{d\,t_g}{d\lambda}\,\Delta\lambda = -\frac{V}{\lambda}\frac{dt_g}{dV}\Delta\lambda = -\Delta\lambda\frac{VL}{\lambda\,C}n_1\Delta\frac{d^2(Vb)}{d\,V^2} \quad (1.29)$$

L et Dg be the guide dispersion parameter:

$$D_g = \frac{\tau_g}{\Delta\lambda\,L} = -\frac{n_1\Delta\,Vd^2(Vb)}{C\lambda dV^2} \quad (1.40)$$

Therefore, by integrating equations (1.29) and (1.30) defining the dispersion of the material and the guide in equation (1.18), we express the chromatic dispersion in the form:

$$D_{ch} = -\frac{n_1}{C\lambda}\,\Delta V\frac{d^2(Vb)}{d\,V^2} - \frac{\lambda}{C}\frac{d^2 n_1}{d\lambda^2} \quad (1.41)$$

Equations (1.15), (1.29) and (1.40) are therefore three different equations expressing the same parameter, chromatic dispersi on. In the general case, the intra modal or chromatic dispersion D (λ) is then defined by:

$$\tau_{max} = D\,(\lambda).\Delta\lambda.L \quad (1.42)$$

And:

$$D(\lambda) = \frac{1}{L}\frac{dt_g}{d\,\lambda} \quad (1.43)$$

Where D (λ) is the chromatic dispersion as a function of wavelength, Δλ is the spectral width, L is the length of the fiber.

2. CHROMATIC DISPERSION LIMITATION

2.1 Long Distances and Hight Flow Rates.

In practice, in optical communication, the phenomena of inter-symbol interference (ISI) are reflected by the distortion of the transmission channel due to chromatic dispersion in the optical fiber.

Therefore, orthogonality is hardly maintained and the individual subcarriers cannot be separated at the receiver.

In this case, an interference phenomenon between the bits may be added if the widening of the pulse exceeds a quarter of the bit time. If the delay τ due to dispersion exceeds the one-bit period Tb, signal degradation due to intersymbol interference does not allow efficient transmission.

A satisfactory criterion is to take a maximum delay such as

$$\tau_{max} = \frac{T_b}{4} = {}^{1}/_{(4B_0)} \qquad (2.1)$$

The group time Tg is usually less than T/4, that is to say,Tg <T/4. In this case, when the guard interval is longer than the impulse response of the channel, or the multipath delay, the ISI can be eliminated.

The product$L_{max}B_0$ will then be constant since the delay due to the dispersion is a linear function of the distance L. The relation between range and flow becomes:

$$\log l_{max} = \log c - \log B_0 \qquad (2.2)$$

2.2 Single-Mode Optical Fiber

For a single-mode optical fiber, the intramodal dispersion Dλ must be considered. The maximum delay is defined in relation (2.37) below.

$$\tau = L\Delta\lambda . D_\lambda \qquad (2.3)$$

The flow B0 is given by the relation (2.3):

$$B_0 = \frac{1}{4\Delta\lambda D_\lambda L} \qquad (2.4)$$

Δλ: is the spectral width of the source.

2.3 Concept of Group Time

During the excitation of a large-core optical fiber, by way of example, by a pulse, the light energy thereof is distributed over a large number of rays which propagate along different optical paths along the optical fiber. For a step index fiber, the length of these paths depends on the angles of incidence θ(i) of rays at the coresheath interface θ(i) of rays at the coresheath interface. Each ray Ri is associated with an angle θ(i) and with a mode Mi. A mode Mi is a transverse distribution of energy, invariant, by axial translation, which results from the interference of the waves associated with the incident ray Ri. The group time, or group delay tg, is defined as the time required for a pulse to propagate in a fiber of length L.

$$t_g = \frac{L}{v_g} \qquad (2.5)$$

With:

vg, the associated group speed, is defined by:

$$v_g = \left(\frac{d\,\omega}{d\beta}\right) \qquad (2.6)$$

The group speed is given by the derivative of the pulsation ω the pulsation with respect to the derivative of the propagation constant β. We can calculate the axial propagation constant from the wave vector $\vec{k}$ whose definition is as follows:

$$||\vec{k}|| = n_1 \|\overrightarrow{k_0}\| = \frac{2\pi}{\lambda} n_1 \quad (2.7)$$

With: $\overrightarrow{k_0}$ is the wave vector in vacuum. The propagation constant β is given by the following relation:

$$\beta = k_0 \, n_1 \cos\theta = n_1 \frac{10}{c} \cos\theta \quad (2.8)$$

Let us take a pulsation ω around ω0, we can determine tg by its limited expansion:

$$t_g = L \left[\frac{d\,\beta}{d\,\omega} \middle| \omega = \omega_0 + (\omega - \omega_0) \frac{d^2\beta}{d\omega^2} \middle| \omega = \omega_0 \right] \quad (2.9)$$

In this equation (2.55) the first term describes the intermodal dispersion which is obviously zero in a single mode fiber and the second term represents the chromatic dispersion due to the different propagation times of the spectral components of the pulse.

3. MODELING AND SIMULATION UNDER THE MATLAB ENVIRONMENT

3.1 Network Configuration Under Study

3.1.1 III.1.1 Local network

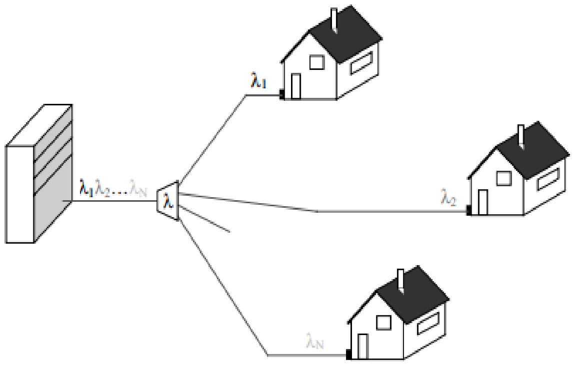

Fig 1: Wavelength division local network.

This method has the advantage of allowing continuous development of the network by adding new services or new subscribers simply by inserting a new wavelength.

3.1.2 Code division multiple access (CDMA)

Code Division Multiple Access (also known as Code Division Multiple Access, CDMA), based on the assignment of a code to each station or user.

Each bit corresponding to 1 is replaced by a sequence of M slots, different for each user and defined as the signature (code) of the latter. A large number of messages can therefore be sent on the same transmission line. The recipient will be able to decode the signal addressed to him among all the information transmitted.

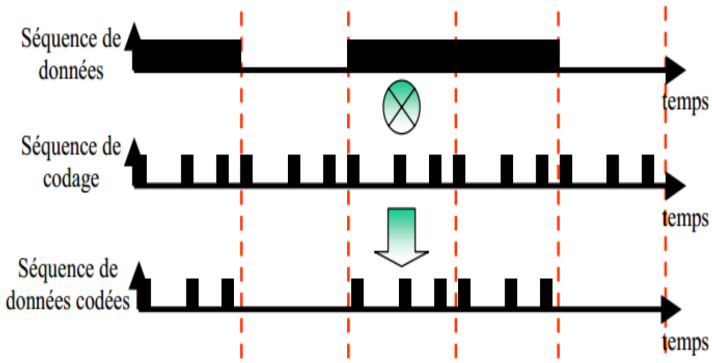

Fig 2: System using the CDMA technique.

This technique is experiencing a real boom in the field of cellular telephony, and research is currently being carried out to apply it in the optical field.Parameters of chromatic modeling

3.1.3 Time analysis of bit time

Table 1. Chromatic dispersion values of the different fibers standardized by ITU-T (source: ITU,2010).

Fiber type	Chromatic dispersion (ps / nm.km)	
	λ =1310 nm	λ =1550nm
9/125 G.652	0	17
9/125 G.653	-15	0
9/125 G.655	-12	3

Considering the different values defined by the ITU, in the table described above, with the chromatic dispersion given by the value.

$$D_{(\lambda)} = 17\, ps/nm.km$$

The spectral width for example of a DFB laser diode is equal Δ (λ) = 0.05nm. We can calculate the group differential delay τ_max with a tolerance of 25% of the bit time as recommended in the literature. Is:

$$\tau_{max} = \frac{T_b}{4} \quad (3.1)$$

With:

$$\mathrm{B} = \frac{1}{T_b} \quad (3.2)$$

So we have

$$T_b = \frac{1}{4B} \quad (3.3)$$

This bit time versus bit rate formula allowed us to calculate the group differential delay respectively with the normalized B bit rates: 2,5 Gbit/s ; 10 Gbit/s ; 40 Gbit/s ; 160 Gbit/s.

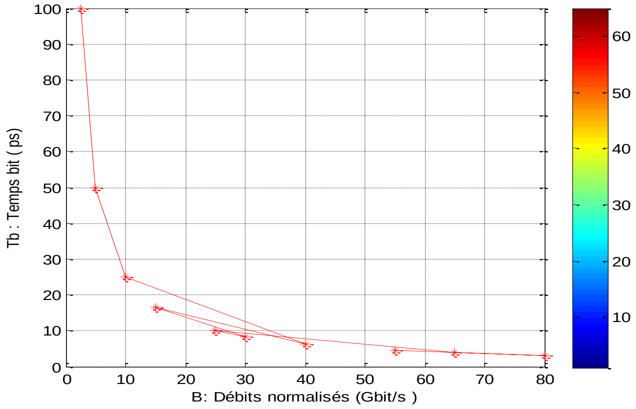

Fig 3: Simulation of bit time as a function of bit rates.

3.1.4 Analysis of the spans according to the dispersion.

These different bit time values allowed us to determine the different ranges, depending on the chromatic dispersion, the spectral width and the bit rate. The different staves (L) are respectively:

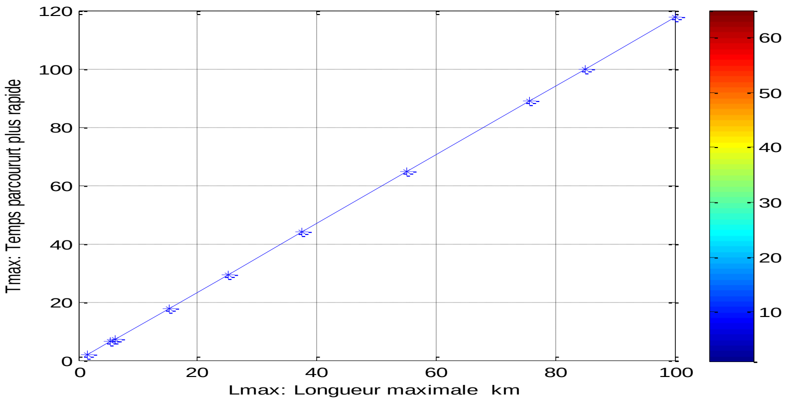

Fig 4: Simulation of the maximum time as a function of the maximum length.

3.1.5 Analysis

On the basis of these various calculated data, we verified the values of the standardized bit rates in the optical network.

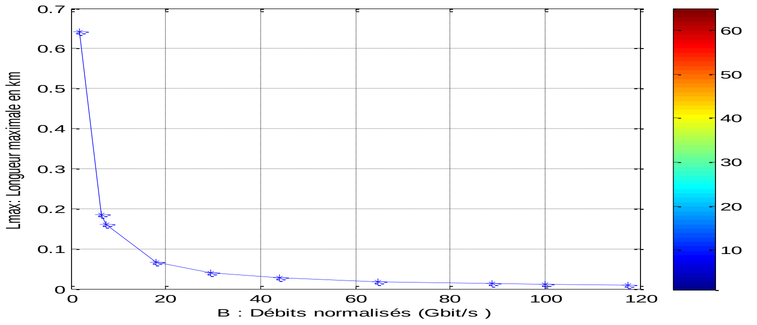

Fig 5: Simulation of the maximum length as a function of standard flow rates

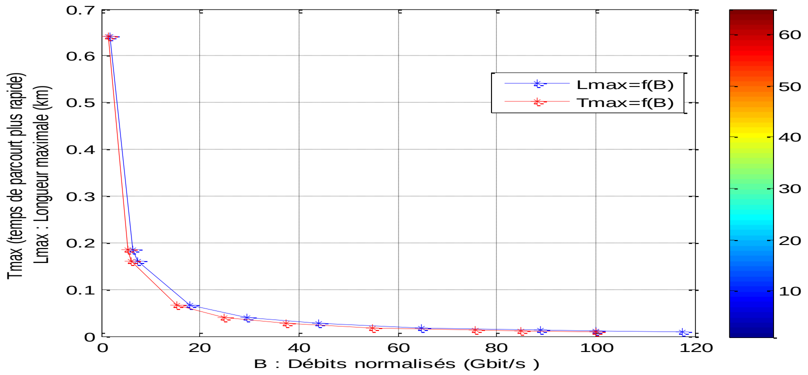

Fig 6: Simulation of the maximum length as a function of the standardized flow rates.

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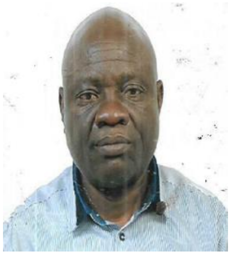
BIOGRAPHY



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