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Research Article

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Modeling of an Optical Fiber Amplifier and Compensator of Chromatic Dispersion in the Telecommunication Network of the City of Kinshasa

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Abstract The main problem on an optical transmission is the chromatic dispersion of the fiber. In this article, we model the dispersion of an amplifying optical fiber in the telecommunications network of the city of KINSHASA. This dispersion is low, of the order of a few tenths of ps/km for a standard single mode fiber. In the case of dispersion compensator fibers, we seek to obtain large values of figure of merit (of the order of a hundred ps/(nm.dB) at 1310 nm) reflecting the good behavior of the fiber. The representation of the chromatic dispersion of a dispersion compensator for 4 modes as a function of wavelength shows that the LP02 mode presents a low dispersion.

Keywords Modeling, fiber optic amplifier, chromatic dispersion, City of Kinshasa

1. Introduction

Among many countries, the Democratic Republic of Congo uses optical link infrastructure. Subscribers are asking for the deployment of an optical network for data use. However, problems related to this optical infrastructure are technically abundant. On a medium and long distance transmission, the losses encountered in the fiber range up to 20 dB/km [1][2][3].

In recent years, fiber optics, having supplanted coaxial cable, has become one of the most widely used media for transporting all types of data (audio, video, Internet) [4][5]. This choice is due to the sustained efforts of researchers in the field of optical telecommunications. Until the beginning of the 90's, the amplification in long distance lines was ensured by optoelectronic devices which required an electrical-optical conversion at the input and an optical-electrical conversion at the output, which limited the throughput of the networks to that of the repeater-regenerators (2Gbit/s at best) [3][6][7]. The advent of rare earth doped fiber amplifiers and in particular erbium (EDFA for Erbium Doped Fiber Amplifier) has made it possible to exceed these data rates since the mid 90s [7].

The positioning and order of the amplification and chromatic dispersion compensation modules within the line in the city of KINSHASA pose optimization problems in terms of the quality of reception of the signals carried. Indeed, the signal degradation varies according to the type of compensation used (pre, post or symmetrical). In addition, the need to limit production costs, the size and weight of the lines has led to the interest in modeling an optical fiber capable of performing both amplification and dispersion compensation functions. It is in this context that we propose to model an optical fiber amplifier and compensator chromatic dispersion used in the optical networks of the city of KINSHASA.

2. Principle of optical amplification

The principle of an optical amplification is based on the two phenomena of electron excitation and stimulated emission. The fiber allows to amplify the signal thanks to an external contribution of energy coming from a pump laser.

A beam is said to be amplified when the number of photons generated by stimulated emission is greater than the number of photons absorbed, or the probability of a photon incident on a given atom to cause the emission of a second photon is greater than the probability of absorbing it. The number of excited atoms must therefore be greater than the number of atoms in the ground state [7].

The interactions of these electrons with incident photons of wavelength λ then cause electron-hole recombinations following a classical stimulated emission process, giving rise to other photons of identical characteristics. This thus leads to an amplification of the signal along the optical fiber.

There are several types of optical amplifiers, among which, we have the Erbium Doped Fiber Amplifier [8][9]. The most widespread optical amplifier to date is the Erbium Doped Fiber Amplifier (EDFA).

It was first introduced in the mid-1980s. It is a device comprising in a single compact box the doped fiber, the pump laser which produces a very high power light energy and the necessary passive optical components. It is based on the phenomenon of stimulated emission [9][10].

Finally, doped fiber amplifiers have a wide bandwidth for which the gain is almost identical, which makes them interesting in the perspective of amplifying several wavelength division multiplexed signals (WDM) simultaneously. It is today the most mature optical amplification technique and the only one present in installed systems. Their main advantages are :

Amplification of several wavelengths at the same time;

typical bandwidth of 4 THz (40 nm), which can be further improved by combining several levels of different dopants in the fiber so as to shift the spectral band (currently covers the C and L bands);

Point amplification (less than 50 m of Erbium fiber);

Relatively low pumping power (a few tens of mW) allowing to obtain high gains (25 dB to 45 dB) to compenasate losses linked to several tens of kilometers of fiber.

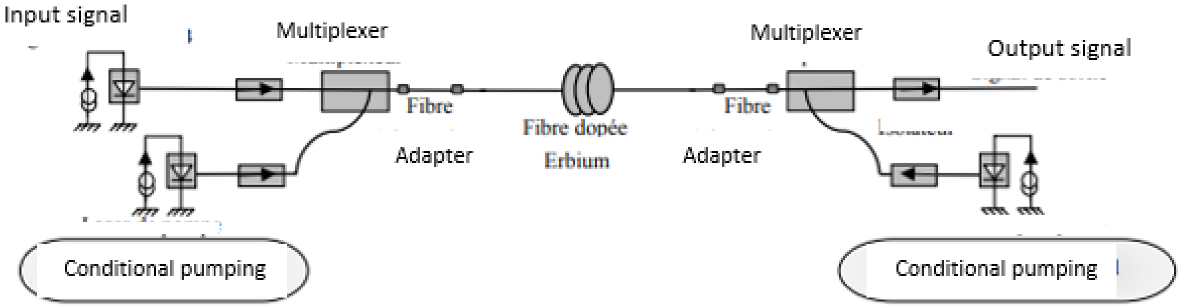


Figure 1: Structure of an Erbium-doped fiber optical amplifier with bidirectional pumping

3. Modeling parameters

3.1 Chromatic dispersion

In single-mode optical fibers whose profile is rotationally symmetrical, chromatic dispersion is the main cause of pulse broadening. Let's define a few terms before starting the study of this dispersion. The group index, N is such that:

$$N = \frac{c}{V_g} \quad (1)$$

Let n_e be the effective index of this mode at the given wavelength:

$$n_e = \frac{\beta}{k_0} \quad (2)$$

$$N = n_e + k_0 \frac{dn_e}{dk_0} \quad (3)$$

The group time is given by the formula (4):

$$t_g = \frac{L}{V_g} = \frac{L}{c}\frac{d\beta}{d\left(\frac{2\pi}{\lambda}\right)} = -\frac{L\lambda^2}{2\pi c}\frac{d\beta}{d\lambda} \quad (4)$$

The temporal elongation τ is defined by:

$$\tau = \frac{dt_g}{d\lambda}\Delta\lambda \quad (5)$$

With: Δλ, spectral width of the pulse. The chromatic dispersion D_{chrom} can then be defined by:

$$D_{chrom} = \frac{\tau}{L\Delta\lambda} = \frac{1}{L}\frac{dt_g}{d\lambda} = -\frac{2\pi c}{\lambda^2}\beta_0 \quad (6)$$

With group speed dispersion:

$$\beta_0 = \frac{\partial^2\beta}{\partial\omega^2} = \frac{\partial}{\partial\omega}\left(\frac{\partial\beta}{\partial\omega}\right) = \frac{\partial}{\partial\omega}\left(\frac{1}{V_g}\right) \quad (7)$$

The propagation constant of a mode in an optical fiber is given by the relation (8)

$$\beta = k_0.n_e \quad (8)$$

The transit time tg is written as :

$$t_g = \frac{L}{c}\frac{d\beta}{d\omega} \quad (9)$$

Therefore, the working time tg can be written as:

$$t_g = \frac{L}{c}\frac{d\beta}{dk_0} = \frac{L}{c}\frac{[k_0(n_2 + bn_1\Delta)]}{dk_0} \quad (10)$$

$$t_g = \frac{L}{c}\left[n_2 + n_1\Delta\frac{d(bk_0)}{dk_0}\right] \quad (11)$$

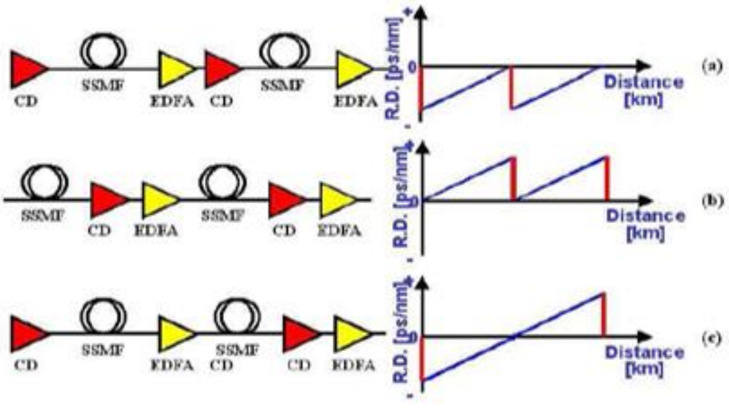
So :

$$dk_0 = \frac{dV}{a.n_1\sqrt{2\Delta}} = \frac{dV}{A} \quad (12)$$

$$t_g = \frac{L}{c}\left[n_2 + n_1\Delta\frac{d\left(\frac{V.b}{A}\right)}{d\left(\frac{V}{A}\right)}\right] = \frac{L}{c}\left[n_2 + n_1\Delta\frac{d(V.b)}{d(V)}\right] \quad (13)$$

3.2 Positioning of the compensation and amplification modules

Dispersion compensating modules are therefore used to solve crosstalk problems.



CD for chromatic dispersion compensations

Figure 2: Three chromatic dispersion compensations.

These modules are characterized by a high negative value of their dispersion which compensates the positive dispersion of a long standard fiber length. To combat the linear attenuation which is the other parameter limiting the propagation distance, optical amplifiers are used. At 1310 nm, the conventional gain of about 30 dB can compensate for the loss of about 150 km of fiber. Signal degradation in these systems is due to the combined effects of dispersion, Kerr-type nonlinearities and spontaneous emission amplification caused by periodic signal amplification at each line regeneration step. Therefore, it is necessary to precisely control these two characteristics. Three kinds of dispersion compensation are possible, pre-, post- and symmetrical as shown in figure 2.

4. Results

In this section, we present the simulation results of the optical fiber amplifier of the Kinshasa telecommunication network.

Figures 3 and 4 show the effective index of the central core of the optical fiber as a function of wavelength (Figure 4) and the effective index of the cladding of the optical fiber as a function of wavelength (Figure 5).

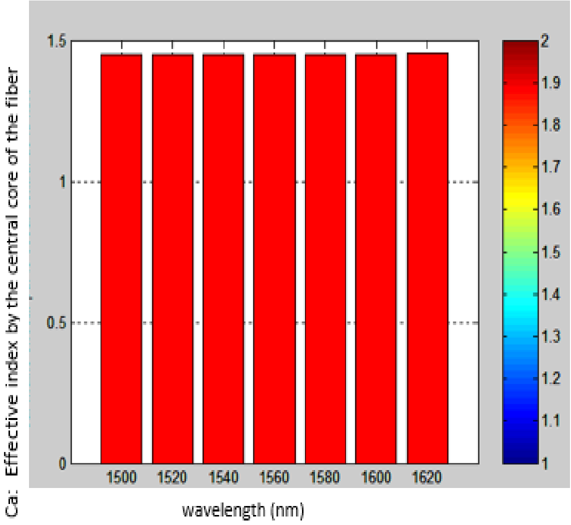


Figure 3: Effective index of the central core of the optical fiber

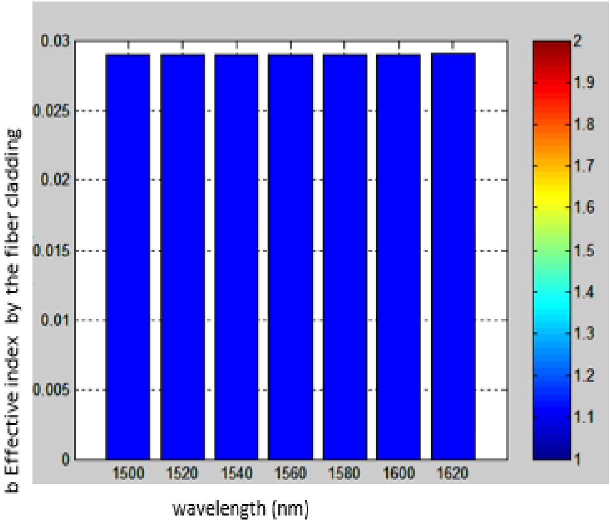


Figure 4: Effective index of the optical fiber cladding

In Figure 5, effective index of the structure mode as a function of wavelength is shown. We observe that the effective index is constant over the entire band.

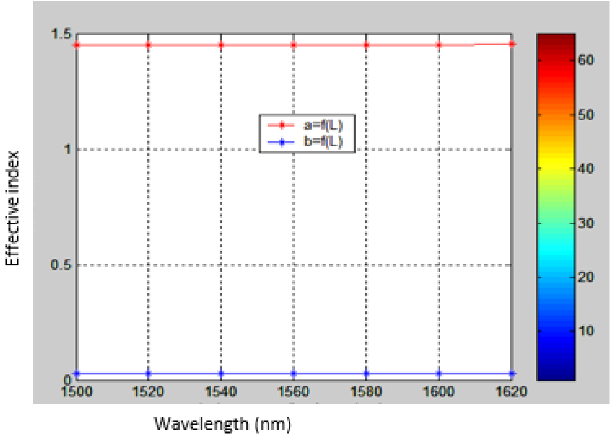


Figure 5: Effective mode index of the structure as a function of wavelength

In figure 6, we have represented the variation of the chromatic dispersion as a function of wavelength in the case of a fiber with two concentric cores. This chromatic dispersion which intervenes as the second derivative of the effective index of the mode of the equation structure is then strongly negative at 1550 nm for a value of -4000 ps/(nm.km).

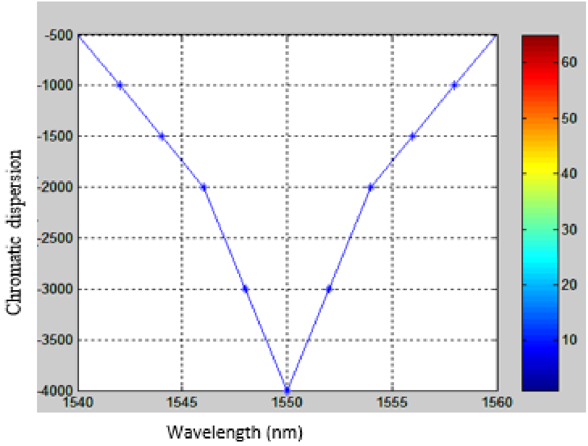


Figure 6: Chromatic dispersion as a function of wavelength in the case of a fiber with two concentric cores

In figures (7) and (8), we have plotted the chromatic dispersions of a compensator using the LP01 mode for figure (7) and LP02 for figure (8) as a function of wavelength. We note that the dispersion decreases when the wavelength increases for these two modes. It is lower for mode LP02 and value is -875.

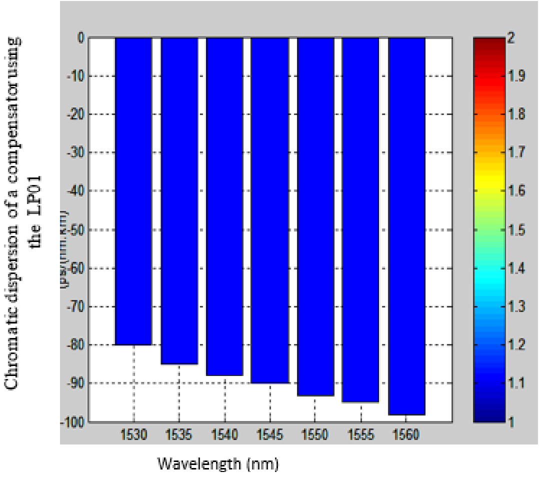


Figure 7: Chromatic dispersion of a compensator using the LP01

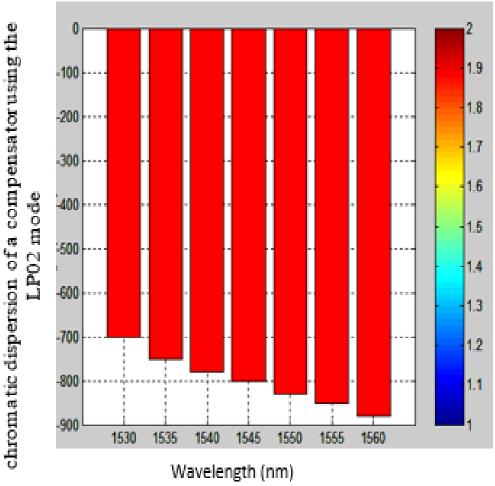


Figure 8: Chromatic dispersion of a compensator using the LP02 mode

Figures (9) and (10) show the variation of chromatic dispersion of a compensator using the LP11 mode (Figure 9) and LP21 (Figure 10) as a function of wavelength. It is low for the LP21 mode and value is -275.

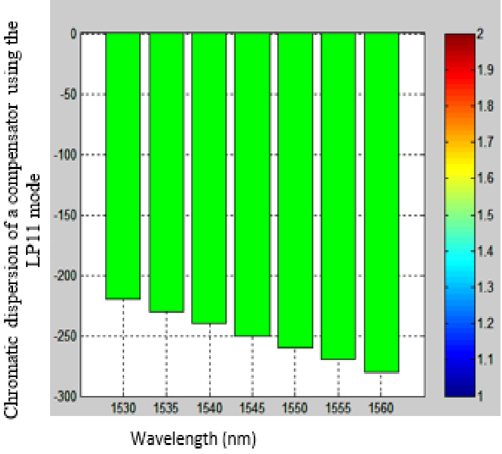


Figure 9: Chromatic dispersion of a compensator using the LP11 mode

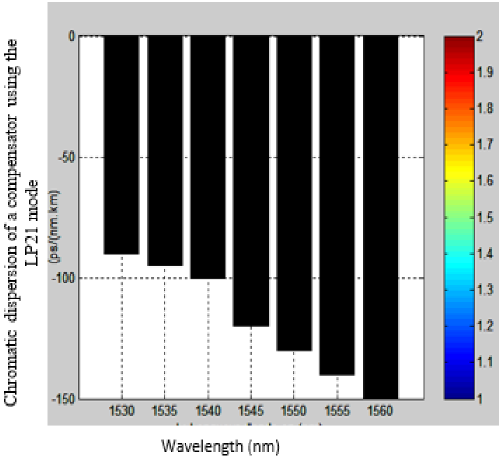


Figure 10: Chromatic dispersion of a compensator using the LP21 mode

In figure 11, we have made a comparison on the representation of the chromatic dispersion of a dispersion compensator for 4 modes as a function of the wavelength. We notice that the mode influences considerably the variation of the chromatic dispersion and the LP02 mode presents a weak dispersion compared to the other modes.

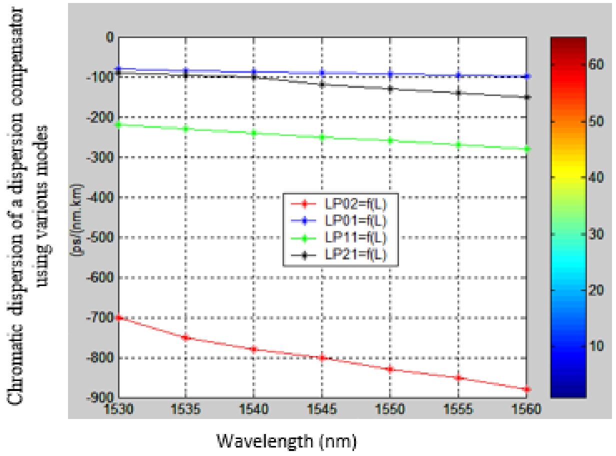


Figure 11: Chromatic dispersion of a dispersion compensator using various modes

Figure 12 shows the variation of the effective absorption cross section as a function of wavelength.

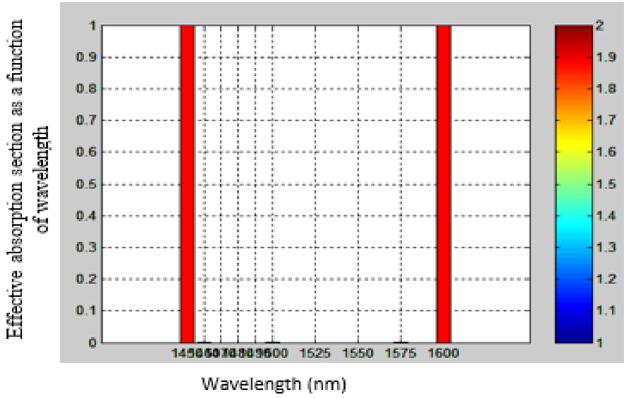


Figure 12: Effective absorption section as a function of wavelength

Figures 13 and 14 represent the variations of the effective sections of emission (figure 13) and absorption (figure 14) according to the wavelength. These two figures present peaks at 1560nm.

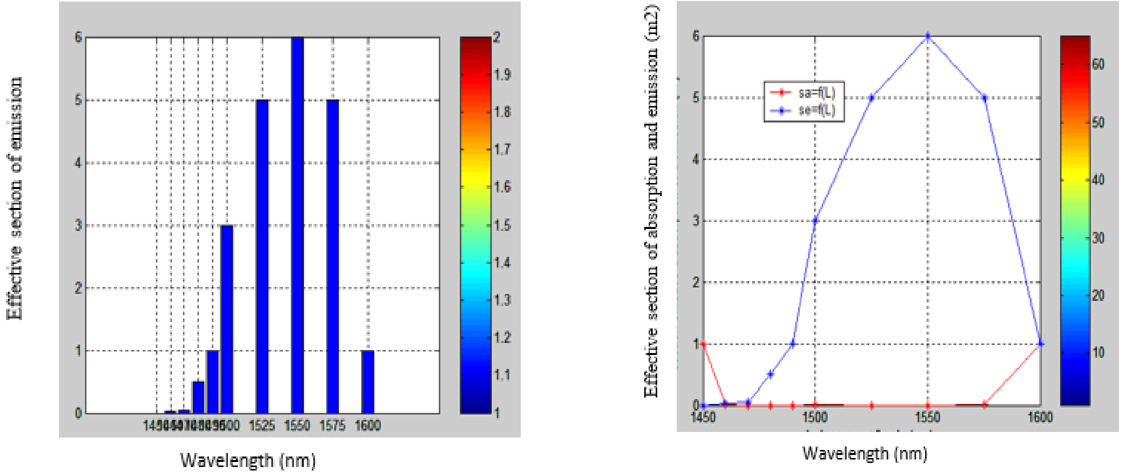


Figure 13: Effective section of emission as a function of wavelength

Figure 14: Effective section of absorption and emission as a function of wavelength

On figure 14, the variation of the refractive index of pure silica as a function of the wavelength is represented. We note that the refractive index does not influence the wavelength.

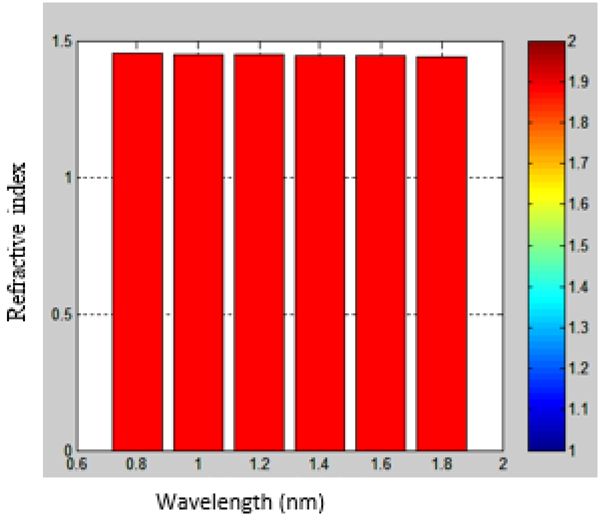


Figure 15: Refractive index of pure silica as a function of wavelength

Figure 16 shows the variation of the optimized optical fiber at the first time as a function of wavelength. The group time shows a minimum value at 1.4nm and maximum at 2nm.

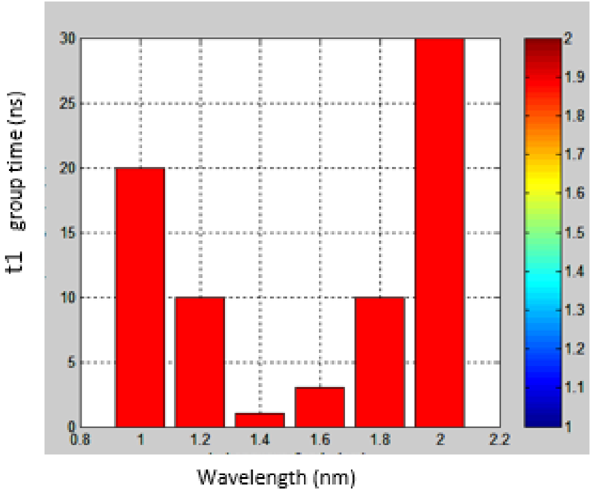


Figure 16: Optical fiber optimized at 1310 nm

In contrast to the optimized fiber at the first time, Figures 16 and 17 show this variation at the second time. They show a minimum value at 1.6nm.

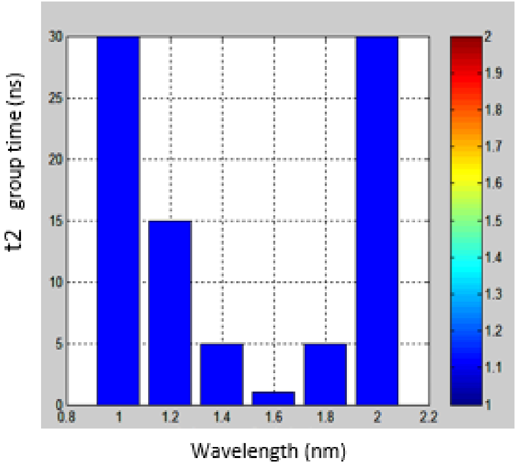


Figure 16: Optical fiber optimized in the second time at 1310 nm

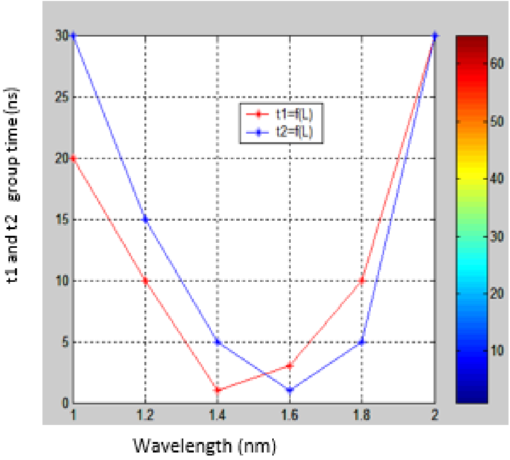


Figure 17: Optimized two-stroke optical fiber at 1310 nm

5. Conclusion

This article consisted in modeling an optical fiber amplifier and compensator chromatic dispersion in the telecommunication network of the city of Kinshasa in DRC. We found that symmetric dispersion compensation influences the transmission quality.

The concept of polarization dispersion is more difficult to understand than chromatic dispersion because of the random coupling of the polarization modes. This phenomenon makes a statistical analysis of the polarization dispersion necessary, with the immediate consequence that the value obtained (in picoseconds) is only an average value.

References

[1]. Le Brun Christine, ″COMSIS: Modeling of component and application to the simulation of optical communication systems″, Applied Optics, September 1998, Vol. 37, n°26, pp. 6059-6065.

[2]. Rice S.O., ″Envelops of narrow-band signals″, Proc. of the IEEE, July 1982, Vol. 70, n° 7.

[3]. Picinbono B. et Martin W., ″Représentation des signaux par amplitude et phase instantanées″, Annales des Télécommunications, Mai-Juin 1983, Vol. 38, n° 5 et 6.

[4]. Helms H.D., ″Fast Fourier transform method of computing difference equations and simulating filters″, IEEE Transmission Audio Electroacoustic, 1967, Vol. AU-15, pp. 85-90.

[5]. Allen J.B., ″Fastfilt: an FFT based filtering program″, Programs for Digital Signal Processing, IEEE Press, 1979, Sec. 3.1, pp. 1-5.

[6]. Joindot Irène et Michel, Les Télécommunications par fibres optiques, Collection Technique et Scientifique des Télécommunications, Paris: Dunod et CENT-ENST, 1996.

[7]. Irène et Michel Joindot « Les télécommunications par fibres optiques » 1996 DUNOD et CENT-ENST, Paris.

[8]. Pierre Lecoy « Télécoms sur fibres optiques, 3e edition » 2008 Lavoisier.

[9]. Cédric Chluda « Bruit basse et moyenne fréquence des amplificateurs optiques distribués à effet Raman »Thèse de doctorat Université Montpellier II 2006.

[10]. Julien Maury « Etude et caractérisation d’une fibre optique amplificatrice et compensatrice de dispersion chromatique » Université de LIMOGES 2003.