Design of Single-Mode Pulse Equalization Optical Fibers

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ABSTRACT

A simple pulse equalization technique is described to minimize dispersion in single-mode optical fiber transmission systems. This technique utilizes positive and negative dispersion characteristics of single-mode fibers on both sides of a zero chromatic dispersion wavelength. Temperature effect is also studied in this equalization technique.

I.INTRODUCTION

The growing demand in data transmission, raised in particular by the internet will require the use of optical fibers as transmission media instead of coaxial cables, even at short distances.

Optical transmission systems have great potential for use in multi gigabit long span trunk line systems because of wide signal bandwidth and low loss characteristics. High speed response optical and electronic devices made it possible to realize over 10 Gb/s ultrahigh speed transmission experiments in many places [1].These technologies will be utilized in practical optical communication systems in the near future. In order to increase the total length of the optical communication systems, the 1.55 μm wavelength systems should be used instead of the conventional 1.3 μm systems as the new window is suitable for high bit rate, long haul transmission owing to high capacity and low transmission loss of the fiber at 1.55 μm.

Unfortunately, in this wavelength region the standard single-mode fibers have a typical chromatic dispersion of 15-20 ps/nm.km. The combined effects of this dispersion and the laser chirp result in an intersymbol interference that can cause a significant performance degradation.

One of the solutions is the use of dispersion shifted fiber (DSF) with zero dispersion wavelength around 1.55 μm. However, this is not effective for conventional fiber networks that are already installed with the standard fibers [2].

The idea of using a special dispersion compensating fiber (DCF) to compensate the dispersion in single-mode fiber (SMF) was proposed as early as 1980, where early dispersion compensation experiments used relatively long pulses (≥ 10 ps).This is not the only method for compensation. There are other techniques utilizing chirped fiber Brag gratings, bulk grating and lens pairs, mid span spectral inversion and dispersion compensating fibers [3].

The dispersion compensating fiber which has a negative dispersion coefficient at the signal wavelength is the most practical means to compensate for chromatic dispersion for reasons of manufacturability, stability with temperature changes and wide band dispersion compensating characteristics.

The proposed optical pulse equalizer system consists of a single-mode fiber with a zero dispersion wavelength λ_{0e} such that λ_S (source wavelength) lies between λ_{0e} (equalizer zero dispersion wavelength) and λ_0 (fiber zero dispersion wavelength). So, the transmission fiber and the equalizer have opposite dispersion signs at λ_S. The pulse that is broadened (by a broadening σ) because of the first fiber dispersion is now restored to its original pulse width after the second fiber following the given condition:

$$\sigma_1 + \sigma_2 = 0 \quad , \tag{1}$$

or

$$D_{T1} L_1 + D_{T2} / L_2 = 0 \quad , \tag{2}$$

where:

D_{T1} is the total dispersion parameter at the source wavelength (λ_S).

D_{T2} is the total dispersion of the equalizer fiber at the source wavelength (λ_S).

L_1 is the first fiber length (transmission fiber).

L_2 is the second fiber length (equalizer fiber).

II. BASIC MODEL AND ANALYSIS

II.1. Material Dispersion

The core refractive index n_1 as a function of the wavelength is represented by [4]:

$$n^2 = 1 + \sum_{i=1}^{3} \frac{\lambda^2 a_i}{\lambda^2 - b^2_i} \quad , \tag{3}$$

where a_i and b_i are, respectively, the oscillator strength constants given by:

$$a_1 = 0.6961663 + 0.11070010\, x \quad , \tag{4-a}$$
$$a_2 = 0.4079426 + 0.310321588\, x \quad , \tag{4-b}$$
$$a_3 = 0.8974794 - 0{,}04331091\, x \quad , \tag{4-c}$$
$$b_1 = 0.0684043 + 0.00568306\, x \quad , \tag{4-d}$$
$$b_2 = 0.1162414 + 0.03772465\, x \quad , \tag{4-e}$$
$$b_3 = 9.896161 + 1.94577\, x \quad , \tag{4-f}$$

where x is the doping (GeO_2) percentage.

The material dispersion parameter, D_m, is defined by [4]:

$$D_m = \frac{L\lambda}{c} \frac{d^2 n}{d\lambda^2} \quad , \tag{5}$$

where L is the fiber length and c is the free space speed of light.

II.2. Waveguide Dispersion

The waveguide dispersion is given by [4]:

$$D_w = \frac{v^2}{2\pi c} \frac{d^2 \beta}{dv^2} \quad , \tag{6}$$

where β is the propagation constant that is given for the step index fiber by [5]:

$$\beta = \sqrt{n_1^2 \left(\frac{2\pi}{\lambda}\right)^2 - \frac{(L+2M)^2 \pi^2}{4a^2}} \quad , \tag{7}$$

The total dispersion is defined by:

$$D_T = D_m + D_w \quad , \tag{8}$$

III. RESULTS AND DISCUSSION

The previous model is used in a computer program to determine the material dispersion, D_m, and the waveguide dispersion, D_w, to get the total dispersion.

Figure1 represents the variation of total dispersion D_T in ps/nm.km. The Figure shows that the wavelength (λ=1.55 µm) lies between the two last curves for D_T at x=0.15 and 0.2, λ=1.55 µm is the optimum wavelength for minimum loss. Therefore, one can obtain an optical pulse equalizer at this wavelength.

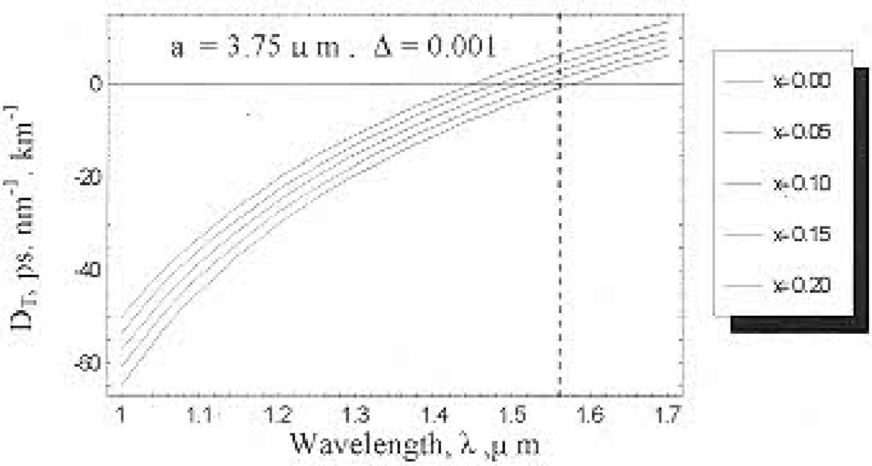

Fig.1. Variation of total dispersion, D_T, with wavelength for different percentage of germania doping in single-mode step index fibers.

Increasing the core radius, a, results in shifting the total dispersion curve (D_T) from the negative region at very small values of a, such as 2.0,2.25,2.5,2.75,3.0 µm towards the positive region at larger values of a such as 3.25,3.5,3.75,4,4.25,4.5,5 µm. Increasing the doping ratio, x results in shifting the zero dispersion wavelength, λ_0, towards higher values as the value of a increases. Starting from a=3 µm, λ_0 exists in non useful region (λ_0 is above1.6 µm). Changing the relative refractive index difference (Δ) from 0.001 to 0.008 results in no noticeable changes in results.

It is well known that the two useful ranges in optical fibers communication systems are at λ=1.55 µm (minimum attenuation) and λ=1.33 µm (minimum dispersion). Therefore, for equalization to occur, the source wavelength (λ_s) must lie between λ_{o1} of the first fiber and λ_{o2} of the second fiber in order that the transmission fiber and the equalizer fiber have opposite dispersion signs at the source wavelength (λ_s).

We have found that, starting from a =3.25 µm, equalization can take place between the first curve (at x = 0) representing the first fiber and any other curve, Fig. 2.

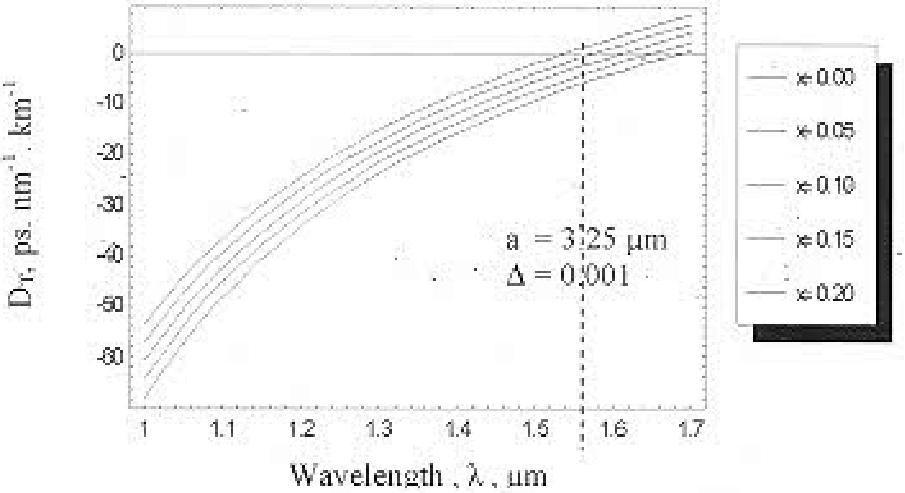

Fig.2. Variation of total dispersion with wavelength for different percentage of germania doping in single-mode step index fibers.

At a =3.5 µm, the equalization can take place between the first curve (at x = 0) representing the first fiber and any other curve but not the next fiber as λ_s = 1.55 µm is not in between these two curves, Fig.3.

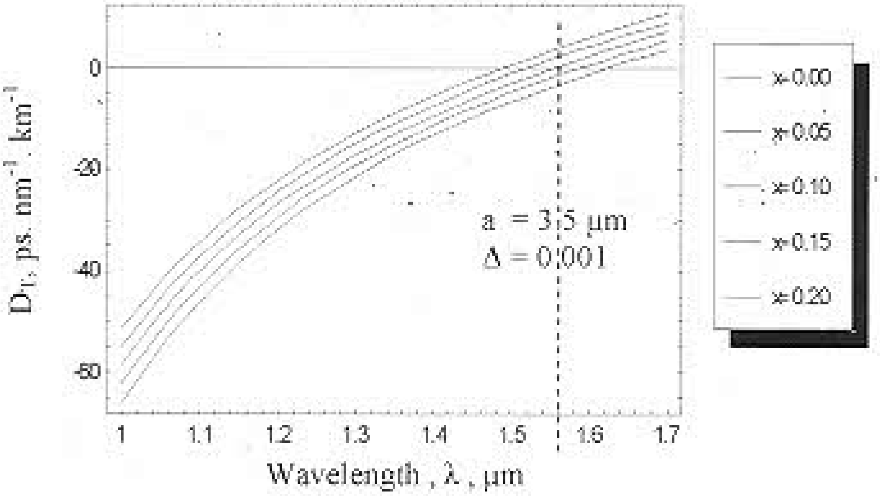

Fig.3.Variation of total dispersion with wavelength for different percentage of germania doping in single-mode step index fibers (at higher value of a rather than that of Fig. 2).

At a=3.75 µm, the equalization can take place between the last curve (at x = 0.2) and any other curve. At a=4 µm , 4.25 µm , 4.5 µm , 4.75 µm and 5 µm, the zero dispersion wavelengths (λ_0) does not exist at 1.55 µm or at 1.33 µm, and so, these values of core radius are not desirable for equalization process.

Samples of results are given in Table 1 for different values of the equalization fiber length (L_2) and its doping ratio at L_1= 1 km and x_1= 0.

λ_s, μm	$L_2(x_2)$, km	x_2	λ_{o1}, μm	λ_{o2}, μm
1.55	0.38792	0.05	1.54002	1.57577
1.55	0.16528	0.10	1.54002	1.61226
1.55	0.10495	0.15	1.54002	1.6495
1.55	0.07704	0.2	1.54002	1.68752

Table 1. Sample of fiber equalizers. a = 3.25 μm , Δ = 0.001

Based on Ref. [4], temperature effect is studied on the value of L_2 through the dependence of the core refractive index n_1 on temperature. The obtained results are displayed n Figs. 4 and 5.

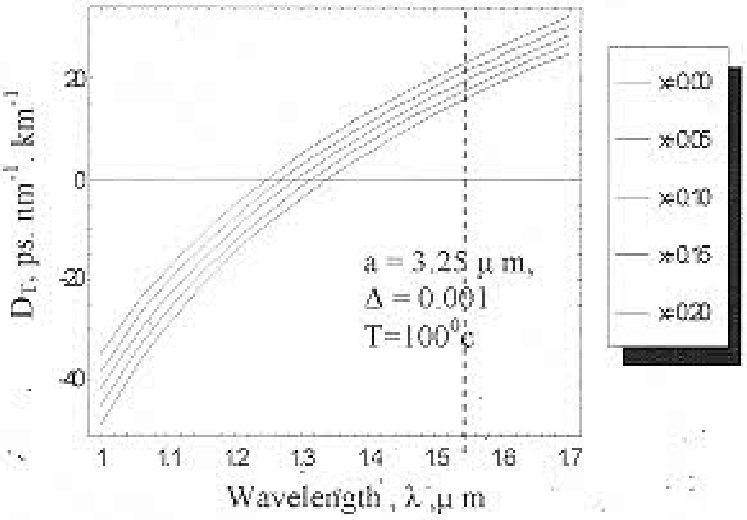

Fig.4.Variation of total dispersion with wavelength for different percentage of germania doping in single-mode step index

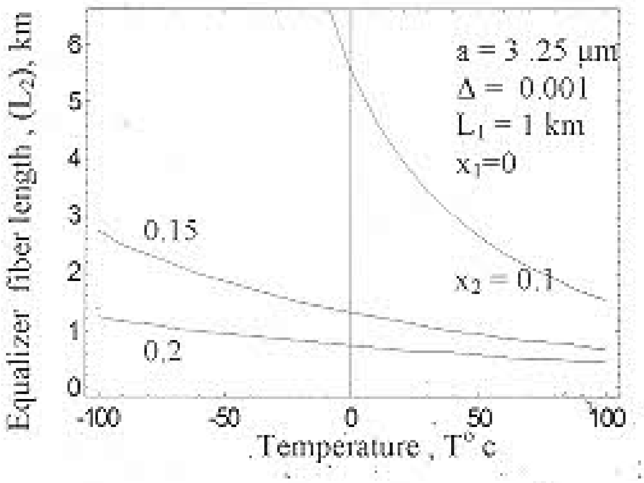

Fig.5. Variation of dispersion equalizer fiber length (L_2) with temperature at different percentage of germania doping in single-mode step index fibers at λ_s=1.55 μm.

From Fig. 5, one can conclude that at a = 3.25 μm, Δ = 0.001, x = 0.1, in the first curve, x = 0.1, no values for L_2 at temperature at 100 ^{0}C and 80^{0}C can exist because the conditions for equalization are not satisfied. However, at x = 0.15 and 0.2, the values of L_2 extends to temperature 100^{0}C.

IV. CONCLUSION

It is much easier to adjust the equalizer fiber length (L_2) than to design the equalizer industrial specifications such as doping ratio (x). Thus, the equalizer fiber can be any single-mode fiber with a relatively large opposite signed (D_T) at the source wavelength. This system depends on the total dispersion equalization and not only the chromatic dispersion as previous work. It is also found that, the equalizer length decreases with the temperature increase at the same doping level, x.

V. REFERENCES

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