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ORIGINAL RESEARCH PAPER

Thermal effect on the optical signal of fiber optics networks

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ABSTRACT

Fiber Optic Network is an advanced and modern system technology, which is used in sending pulses of laser light inside a glass of fiber over long distances, widely used in every environment with various sorts of applications in a different field. It is well-known that the main material of fiber optics is glass, therefore it is typical that the temperature can affect the glass during the thermal expansion. This effect will be applied to the properties of the optical components such as refractive index, radius curvature of the fiber optics layers, and also there is an effect on the data transfer through the fiber optics network units. In this paper, the effect of temperature degree on the optical signal and the functions of the fiber optic network will be simulated, measured, and analyzed. The result will be discussed and the conclusion will show the serious points of thermal effects on the optical signal of a fiber-optic network.

KEYWORDS

fiber optic network, thermal temperature effects, data transfer, thermal expansion

1. INTRODUCTION

The effect of the thermal on the communications system is a clear fact because of the environmental condition of the communication systems (fiber optics is one of them) working in different types of the field [1], such as different temperature degrees (range of high heat temperatures and freezing low temperatures). Therefore, it is very important to measure the effect of thermal on each part of the fiber optics communication system (transmitter source), link (fiber optics), and receiver (photodetector) as shown in Fig. 1 [2].

There would be several sorts of thermal effects which are formed depending on the components of the communication system. In other words, the thermal effect on the system depends on many factors such as the quantity, duration time, material type, and the way of effect applied (direct or indirect) [3].

In the present paper, the effect of temperature degree on the optical signal, components, and the fiber communication network will be simulated and analyzed. As a result, the aberration and dispersion will be measured to indicate the effect it has on the image plane. The objective of this research is to show the thermal effects on the optical signal of the fiber optic communication network, in order to design a fiber-optic network with a minimum loss with heat as possible at backbone networks.

The present paper is structured in paragraph two which presents the related work about thermal effect work that will be discussed, section three presents the optical network structure, section four explains the main fiber optic thermal effect, while section five shows the analysis and the result of the paper. Whereas, the final sixth section will present the conclusion and future work of the paper.

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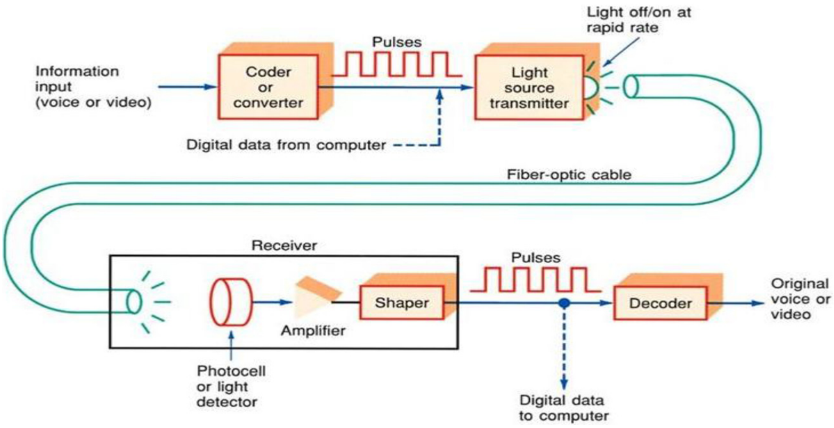

Fig. 1. Fiber optics communication system [2]

2. RELATED WORK

In recent years, many researchers conducted a different type of simulation on the thermal effect on the fiber optic signal. In figure [4], the author explains the reactivity of thermal delay of propagation and phase in fiber optics with a band of hollow-core photonic where the results showed that the propagation delay is completely insensitive to variation of temperature. In figure [5], the propagation delays thermal response and the hollow-core photonic bandgap fibers phase accumulated through adequate fiber design with explanation and the result shows the extraordinary prospects are given by this exotic property. In figure [6], the author shows more temperature tolerance variation using hollow-core in very fast fibers optical communication systems and the results show the transmission of error-free short packets with less than 625ps clock recovery time in 25.6 Gb s^{-1} real-time systems. Finally, in figure [7], a comparison was carried out between the standard single-mode fiber (SMF-28) and the sensitivity of the thermal phase for hollow-core fiber (HCF) 180°C up to room temperature. The results show that the effect of temperature changes on the thermal phase sensitivity of fibers without any coating, while the HCF shows fully insensitive to small temperature fluctuations.

3. OPTICAL NETWORK STRUCTURE

This section will present a fully comprehensive discussion of the optical fiber network structure and its properties.

3.1. Properties of optical signal

As usual, the light is the main source of the fiber optics which generates the optical signal where the light is an electromagnetic wave as a part of the electromagnetic spectrum. The main characteristics of electromagnetic waves are wavelength, frequency, and energy. The electromagnetic spectrum contains light waves, radio waves, microwaves, infrared rays, UV rays, Gama rays, and x-rays [8]. Figure 2 shows the various forms and colors of light waves as a ray (incoherent) or beam (coherent) [9].

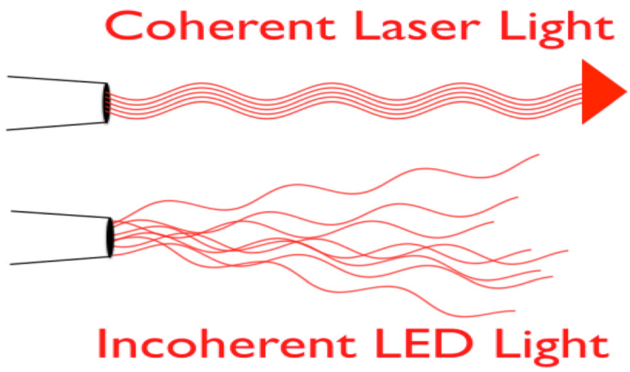

Fig. 2. Coherent vs incoherent light wave [9]

The propagation of the light through the medium counts on Snell's Law, by describing the refraction relationship between two different refractive indexes of materials given by Eq. (1) [10].

$$n1sin\varnothing 1 = n2sin\varnothing 2 \quad (1)$$

whereas n1 and n2 are refractive index for incident medium1 and refracted medium2 respectively, φ_1 *and* φ_2 are incident angle and refractive angle respectively as shown in Fig. 3 [11].

The principle of light travel in any material depends on how fast it travels in it (material) even if it is insulating or has dielectric upon entering. So, the light goes through any material with slow down speed, and the percentage of this decrease depends on the value of refractive index material (of the medium). The speed of light in the material denoted by (v) is less than the speed of the light

in vacuum (c). And the ratio of light speed in vacuum over the light speed in the material will give a value of the refractive index (n) of the material as given by Eq. (2) [11].

$$n = \frac{c}{v} \quad (2)$$

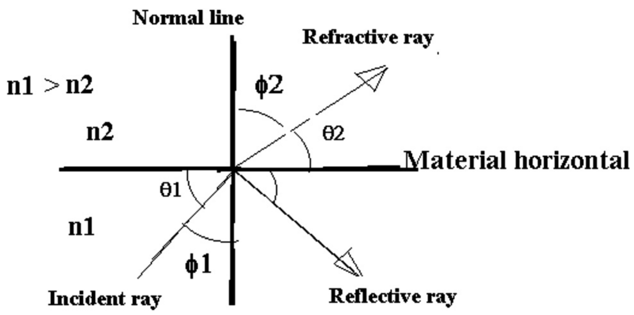

Fig. 3. Light ray behavior (refraction & reflection at material surfaces) [11]

3.2. Light behavior & dispersion

When the incident angle increases, the refraction angle will increase also until the refractive ray will be parallel to the horizontal axis, and any increase after that there will be a total reflection and the angle called the critical angle. This case is called total internal reflection [12] as shown in Fig. 4.

This case happens in the fiber optics when the light is transmuting in it, therefore it will be an aberration and dispersion in the fiber optics signal. To understand the dispersion, we have to imagine two light rays incident on the fiber with different incident angle (ray B perpendicular on the fiber into the center of fiber (core) and ray A inclined) while the fiber has multi-material (refractive index), therefore the two rays will move inside the fiber but with various optical paths, meaning that the ray A will reach the end fiber faster than ray B, due to this, the different separation between ray A and ray B is called dispersion [13] as it is shown in Fig. 5.

The fiber optic has a different layer of refractive index, distributed as a radial distribution, therefore when the light enters the fiber it will move inside the fiber until it reaches the end with dispersion. Because each ray has its optical path and they will not be reached at the end of fiber at same time, therefore the difference in the time of ray moving is equal to Δt [14], so Δt is equal to:

$$\Delta t = \frac{Ln_1}{cn_2}(n_1 - n_2) \tag{3}$$

where n_1 & n_2 are the refractive indexes of the first and second material, L is the length of fiber optics.

In general, the dispersion will be various in fiber optics if it is the single-mode or multi-mode fiber, which are two types of fiber optics [15]. For longer distance and higher bandwidth single-mode

will be used which has a smaller core diameter than the multi-mode core, this property gives less possibility for attenuation, as shown in Fig. 6.

3.3. Networks of fiber optic

The components of fiber optic will be two types, active and passive such as an optical amplifier, coupler, splitter, and multiplexer (WDM, & DE). The difference between passive optical components and active is the passive will work without external power while the active will not work without external power [16].

The network is important to share resources and digital information [17]. For a long period fiber-optic network has been used to transmute large-capacity information. And backbone networks use optical fibers due to their ability to transmit high-speed data of more than 10,000 Mbps (10 Gbps) and provide very high spectrum bandwidth.

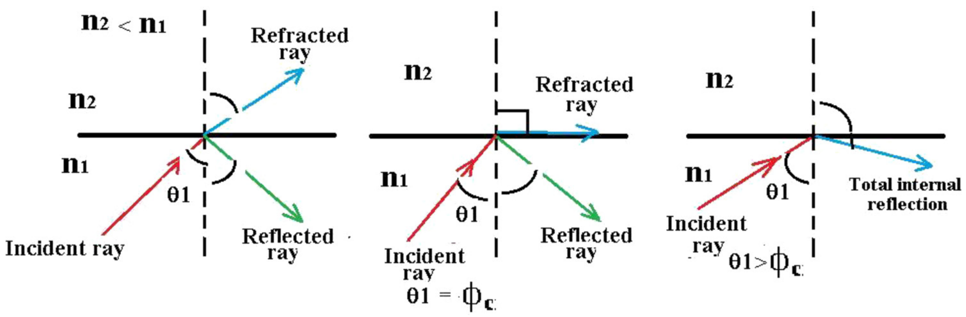

Fig. 4. Shows a critical angle behavior [12]

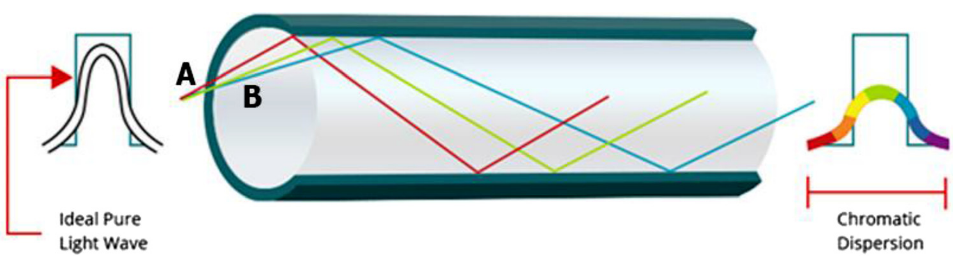

Fig. 5. Dispersion in fiber optics [13]

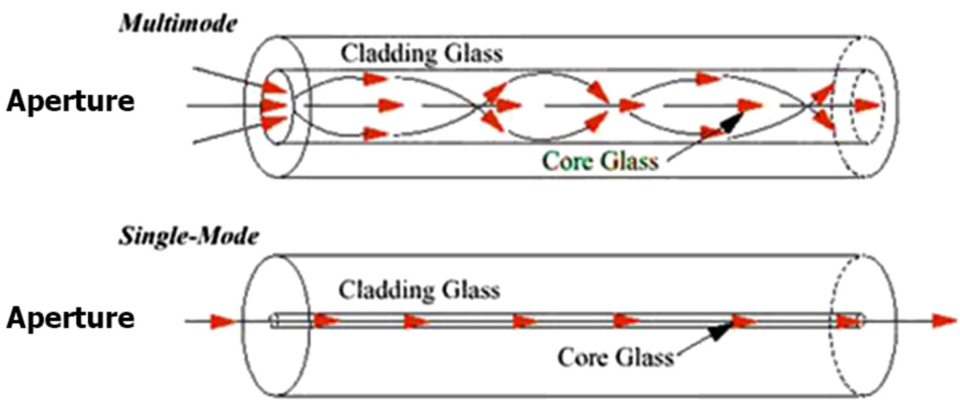

Fig. 6. Structure of fiber optics mode [15]

The network of fiber optics has been used across the countries to transmute huge information as well as fiber optics network which is used in many fields and areas such as broadcasting, military, space, and industry. Figure 7 [18] shows the optical fiber communication networks.

3.4. Fiber optic routers

To connect networks with different Local Area Networks (LANs), routers are needed to join various subnets with IP addresses counting on the network. There are different types of routers depending on their purpose, such as core, enterprise, edge, and branch routers with routing protocols [19].

A router of fiber looks like a gateway that connects two or more networks. There is no limitation in using several routers, (100) routers may be used in one package such as the OSI model, and usually, a router will be in layer 3 of the optical link layers.

Mainly fiber routers are connected to ISP modems. They are used to connect the backbone of the internet as they have fast port connections and can forward a huge amount of data between networks, while a wireless router can be connected to standard devices.

3.5. Wavelength division multiplexing (WDM) system

The WDM is a type of optical multiplexer that is a wavelength deviation multiplexing and it is used with optical communication. Its basic structure is shown in Fig. 8. It offers more boost to the transmission capacity of the fiber. The function of WDM accepts multiple independent wavelength sources (a small difference between them) and then it transmits them in one narrow spectral band in the same fiber without any effect on the information. So, this processing “some time” is called a dense WDM (DWDM).

The advantage of DWDM is the wavelength is spaced properly to avoid channel interference adjusting because if the interference occurs, it produces a distortion in the optical signal. This distortion refers to the difference between the wavelength of the beam center of the light and the characteristics of spectral operating from other optical components because of time and temperature. Furthermore, the distortion produces the dispersion or drift in the pulse of the

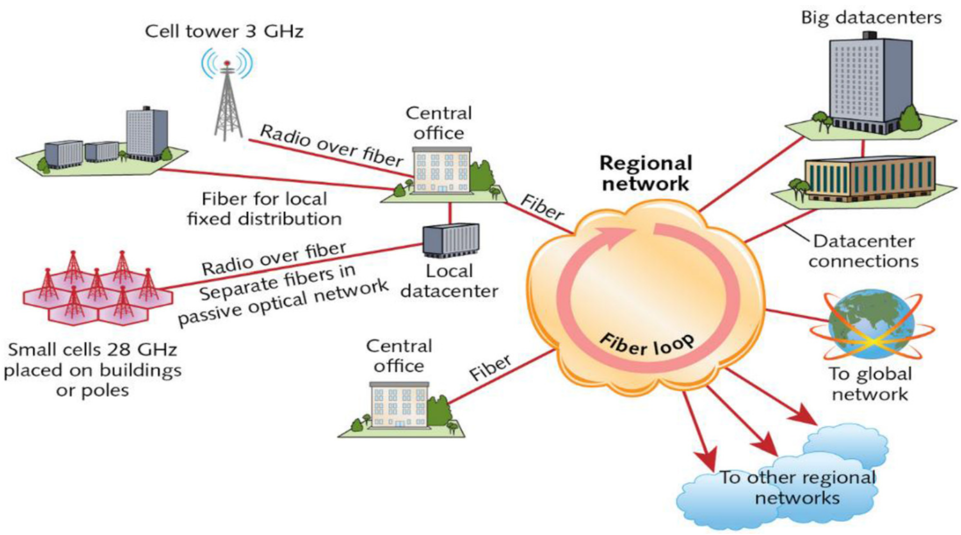

Fig. 7. Fiber optics networks [18]

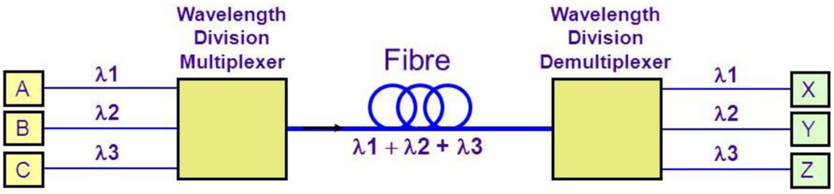

Fig. 8. WDM technology diagram [20]

optical signal, if this dispersion is not treated it will be making wavelength trespass into another spectral band region [21], as shown in Fig. 9 Chromatic WDM Application on FTTA with a guard band between wavelength channels.

3.6. Fiber optic cable

Fiber optic cable contains several single fibers, whereas, each single fiber structure is from the center (middle of the fiber) a core surrounded by cladding, and the buffer coating (jacket). The core is made of a sort of glass (a number of layers, each layer has a value of the refractive index (n), distributed as radially as shown in Fig. 10 which presents a cable of optical fiber with (6) sub optical cable (called loose tube) contains (6) optical fiber diameter 250µm. So, the light (with information) will transmit in every single optical fiber inside the core by optical carrier waves while the cladding keeps the optical signal inside the core by processing called total internal reflection as shown in Fig. 11 [22].

When the light travels in fiber optics, some of the speed will be changed because of rays refraction during passing a variable refractive index (n) of the distribution of the material (according to Snell's law which is [$n_1 \sin\theta_1 = n_2 \sin\theta_2$], whereas, n is the ratio between the speed of light in the vacuum (c) to speed of the light in the material (v). As usual, the speed of the light will be reduced because the light will intersect with the particles (molecules) of the materials. The reason for this is reducing some absorption and the other will be scattered. In this case, it is fair to treat this case will be by using an optical amplifier to raise the power and re-transmitting the optical signal again in the fiber optics as shown in Fig. 11.

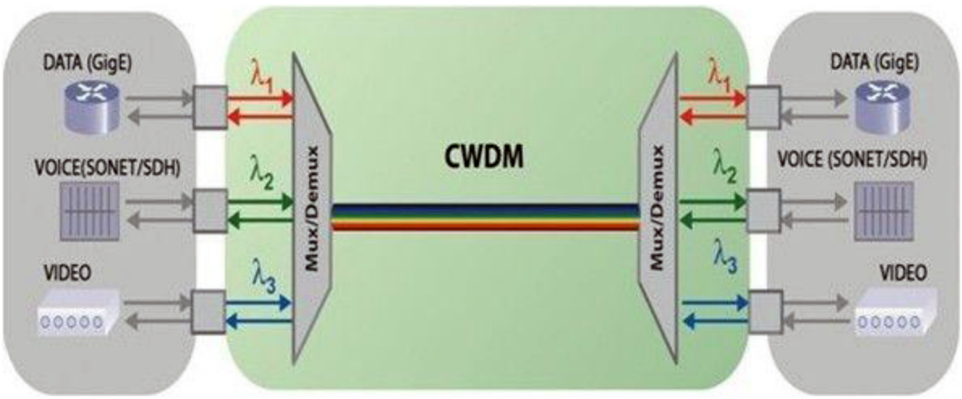

Fig. 9. CWDM application on FTTA [21]

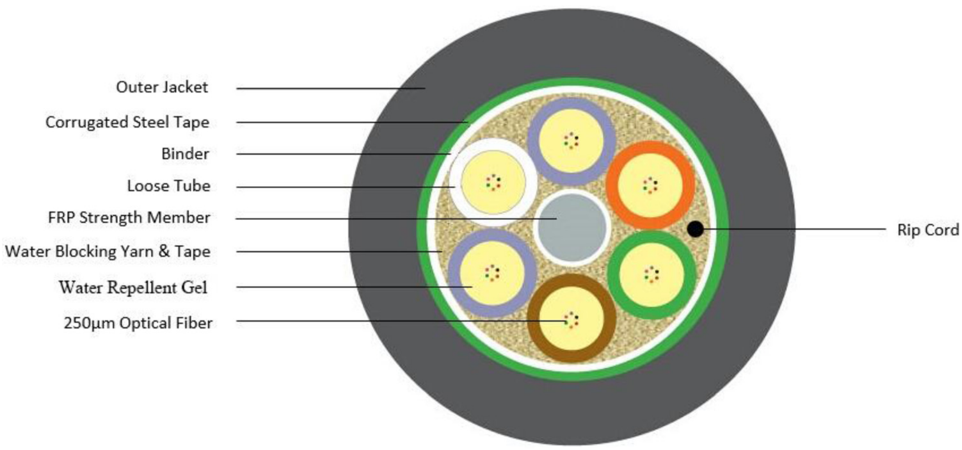

Fig. 10. Optical fiber layers [22]

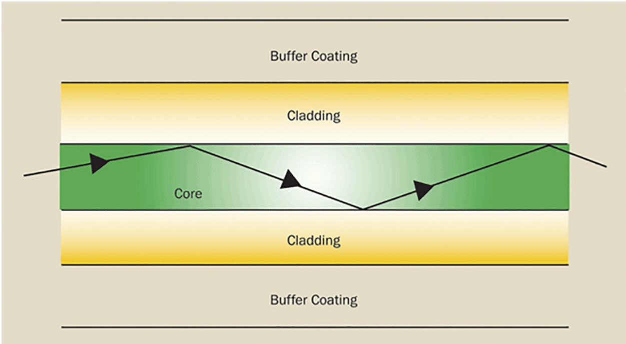

Fig. 11. Transmitting of optical signal in a fiber optic by applying Refraction & Reflection laws [22]

4. FIBER OPTIC THERMAL EFFECTS

The effect of variable temperature degrees will be on the thermal expansion value of the optical component material, i.e., it affects the shape coefficient (q) and position coefficient (p) [23].

While (q) depends on the value radius of curvature for the surfaces of the optical component and (p) depends on the value of the object & image distance [24].

The change in the value of p & q will transfer indirectly to the focal length (f) values because any change in the refractive index (n) of the optical component material will change the value of (p & q). Therefore, f can be calculated from the following equation [23]:

$$f = \frac{K}{n - 1} \tag{4}$$

While K is geometrical constant, any variable in the refractive index will be a variable in the focal length, so any variable in temperature (dT) will be a variable in refractive index (dn) [2, 4], then [23]:

$$\frac{\partial f}{\partial n} = \frac{K}{(n - 1)^2} \tag{5}$$

Finally, any change in the value of focal length will be a change in shape focal point (causing a defocus or distorted image), the variable in the focal length (Δf) [23], as follows:

$$\Delta f = \frac{\Delta nk}{(n - 1)^2} \tag{6}$$

5. RESULTS & DISCUSSION

By using the simulation program (Opti System 15) to set up a circuit as shown in Fig. 12, the circuit with different random values of the dispersion according to variable values of temperature degree was simulated. For each run the output was recorded for both Optical Time Domain Visualizer and Optical Spectrum Analyzer, also simulation parameters were shown in Table 1.

Therefore, four main values of dispersions have been taken as shown in the following Table 2 and shown in Figs 13–15.

Where T_D is the temperature of fiber dispersion for lab-temperature (Room Temperature = 21 °C = 274 K)

By analyzing the layout of Figs 16–19 which displayed the Optical Spectrum Analysis and Optical Time Domain. In Fig. 16 the dispersion value is in minimum value, while it increases randomly until Fig. 19 which has a maximum value of dispersion. The bandwidth of optical spectrum analysis is variable, depending on the dispersion value, which was affected by the thermal temperature. While for

Table 1. Simulation parameters

Parameters	Values
Fiber-optic Cable	Single-mode
Fiber optic Length	50 km
Signal Frequency	193.1 THz
Sample rate	$64x10^{10}$ H
Sequence length	128 bits
Sample per bit	64
Number of samples	8,192
Line width	10 MHz

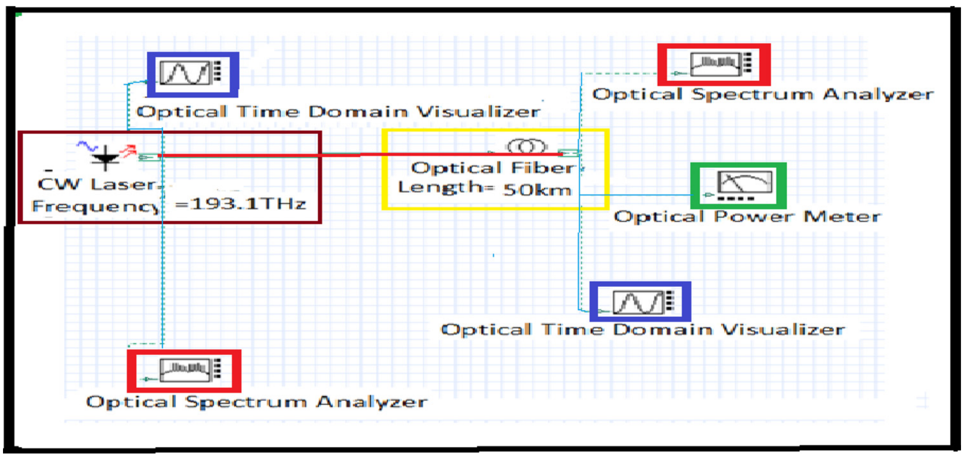

Fig. 12. Practical Diagram of optical fiber connection.

Table 2. Dispersion values

Temp. K T_D	Dispersion	Bandwidth	Peak	Figure number	Pulse Signal
T_D x10	6.75	80%	15	12	1.5 nm
T_D x20	10.70	50%	15	13	2 nm
T_D x30	16.75	90%	15	14	2.3 nm
T_D x40	26.75	75%	26	15	3.5 nm

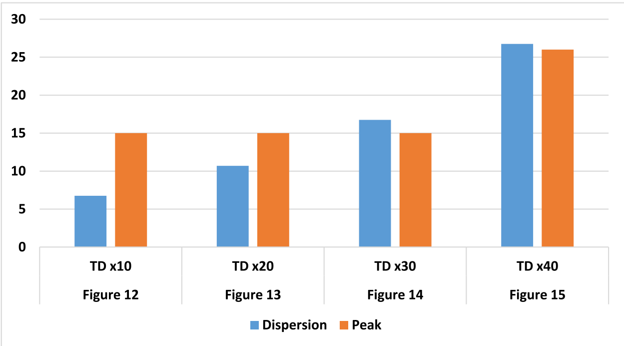

Fig. 13. Dispersion and peak values

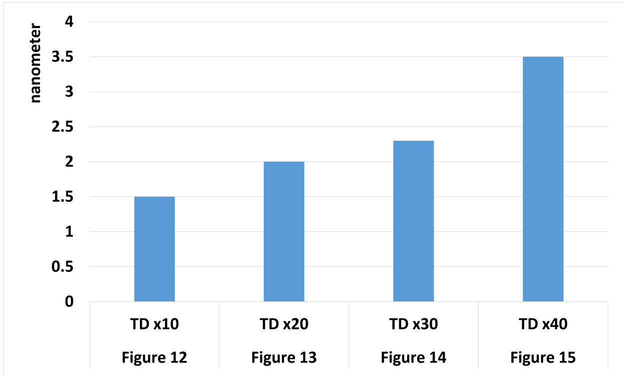

Fig. 15. Pulse signal values

the optical time domain, the pulse of the signal was moved from the minimum value (1.5nm) as seen in Fig. 16 to get the maximum value in Fig. 19 which is (3.5nm) because of the variable value of dispersion.

6. CONCLUSION

The thermal effect on the fiber optics signal takes place during the thermal expansion of the fiber optics material. Of course, this effect will transfer to the dispersion value of the fiber optics. The effective value of thermal expansion is not clear in fiber optics because there are different types of material (that means different refractive index and different thermal expansion for each one) in fiber optics, therefore for this reason the thermal effect will be distributed between these material layers. The amount of the temperature variable does not linearly affect the fiber optics signal because there are many protections against the extra effect such as temperature and force. For example, there is a buffer coating roundabout single fiber and also there is an outer PVC jacket. The variable in the dispersion value is not the same effect on the optical image form as an optical signal, because the tolerance value of imaging is higher than the optical signal. Also, the effect of the dispersion value (which happens of the thermal effect) is not clear, because for each fiber optics magnification there will be some acceptance value of dispersion that does not affect the optical signal (which is within the manufacturing tolerance).

For the future work, we suggest implementing all the work practically to test more values and to get more realistic results.

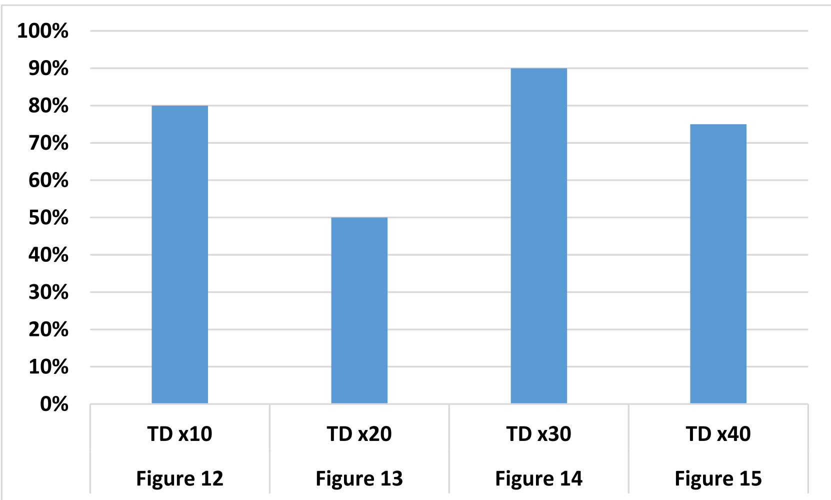

Fig. 14. Bandwidth values

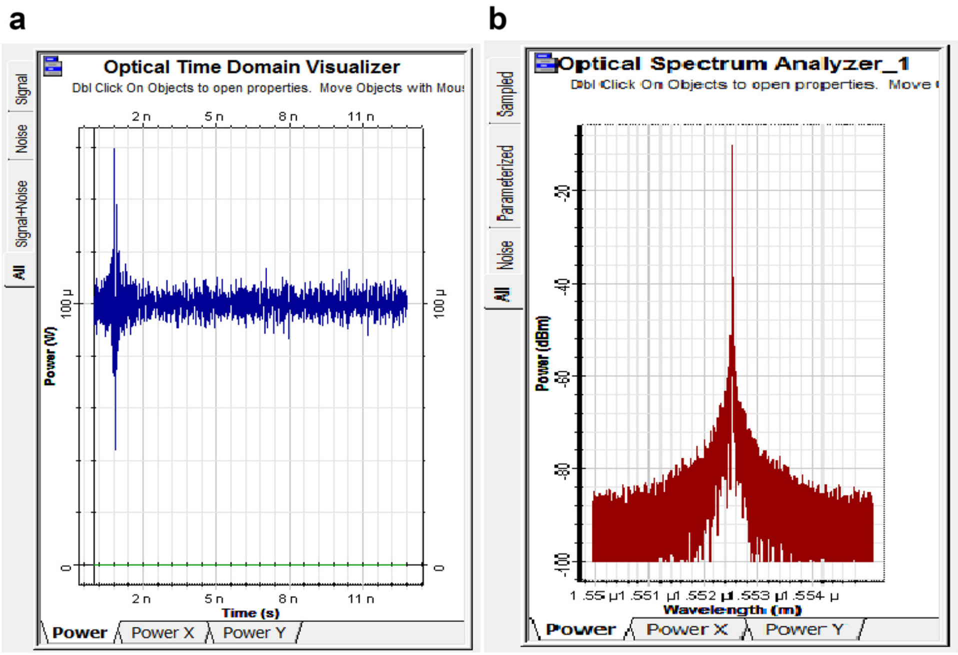

Fig. 16. (a) Optical time domain visualizer, (b) optical spectrum analyzer

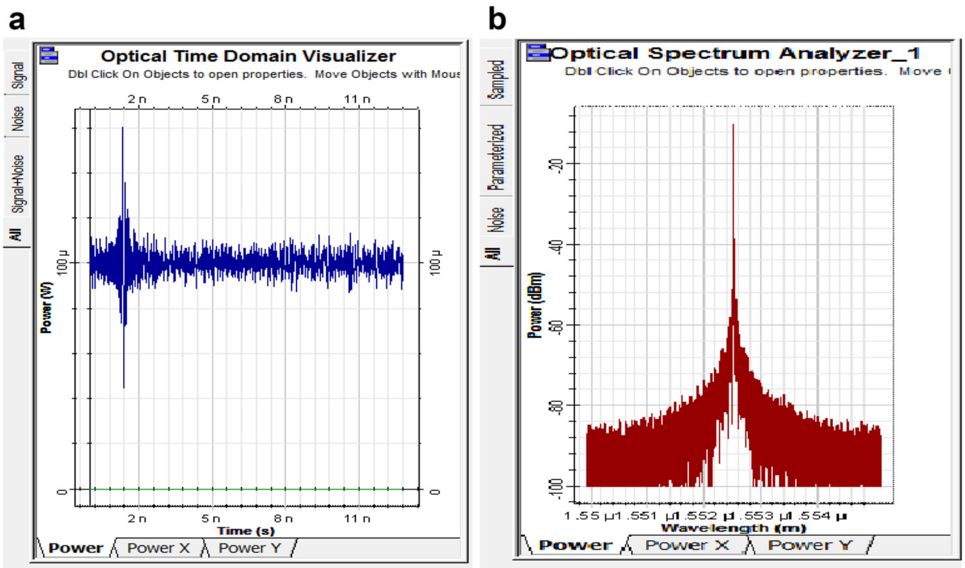

Fig. 17. (a) Optical time domain visualizer, (b) optical spectrum analyzer

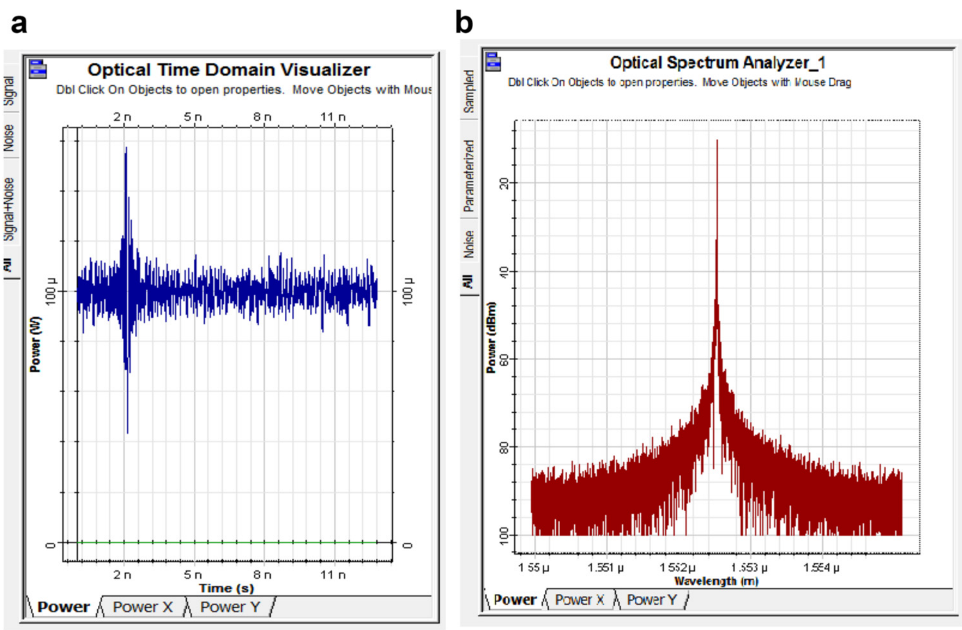

Fig. 18. (a) Optical time domain visualizer, (b) optical spectrum analyzer

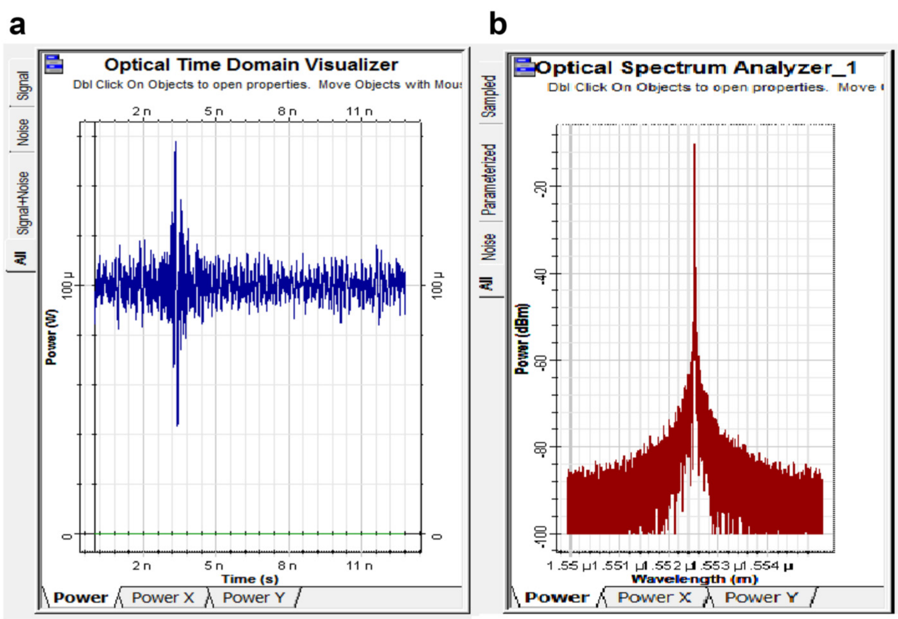

Fig. 19. (a) Optical time domain visualizer, (b) optical spectrum analyzer

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