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Core multi-layer dispersion on single-mode optical fiber

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ABSTRACT

Optical technology has experienced extraordinary developments in recent years and the development of optical fibers continues to be carried out for various applications, namely optical sensors, long-distance communications, and health monitoring so that they can be applied in monitoring high temperatures in petroleum plants. Optical fiber has properties that cannot interfere with electromagnetic waves, which is an advantage compared to conventional cables besides optical fibers are able to transmit data quickly and reach very far across continents. However, the signal in the optical fiber that is carried in the form of pulses can experience widening, this widening is a result of changes in the refractive index, constituent materials, and losses due to fiber optic connection which will decrease the quality of the received signal. One way to reduce the pulse widening in a single-mode optical fiber is to split the fiber core into several layers to obtain zero dispersion in the single-mode optical fiber. Another thing is that we can influence the effect of the inner layer of the fiber core on the desired zero dispersion. After designing the optical core by making several layers, it was found that the dispersion was not found in the 6 and 7 core layers while the fibers with layers 2, 3, 4, and 5 had different wavelengths for zero dispersion. Furthermore, the effective area or area that is passed by the optical signal and the largest fiber mode diameter is obtained on 3-layer fibers with a value of 230.0454 μm^2 and 17.1144 μm each seen from the delay of layer groups 2, 5, 6, and 7 experiencing a group decline for each wavelength while fiber With layers 3 and 4 experiencing an increase in group delay from the experimental data it was found that cores with 6 and 7 layers would not find the desired zero dispersion while optical fibers with the best layers transmit signals were cores with 3 layers.

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1. INTRODUCTION

Fiber optic telecommunications as a data transmission medium has become an important technology for communication today, which is capable of transmitting data in the form of electromagnetic waves across oceans [1], across continents [2], across countries [3], between cities [4], and access to campuses [5]. One type of optical fiber used in transmitting data is single-mode fiber (SMF) which has high transmission capabilities due to the absence of modal noise [6], low attenuation [7], long-lasting [8], and in accordance with integrated optical technology [9]. SMF is the focus of researchers to realize data transmission reaching 100 – 200 Tbit/s [10-12].

Dispersion is the event of light breaking down due to differences in deviation at each wavelength and is also one of the factors that influences signal quality in optical fibers [13-15]. Ideally, in producing smooth communication, the light in the fiber experiences no dispersion or zero dispersion. Therefore zero dispersion is very important in producing a signal without interference [16, 17]. Apart from experiencing light decomposition in the optical fiber, it will also experience weakening or attenuation due to the medium and differences in the refractive index of the optical fiber [18-20].

Limitations in experiments make optic fiber simulation an alternative to determining fiber characteristics that are capable of producing perfect signals without interference [21-23]. Several simulations have been carried out to produce zero dispersion in single-mode fiber. including designing four layers of fiber optic core and cladding at a wavelength of 1.55 μm [24] and fiber optic design at a wavelength of 1.3 μm [25].

In general, dispersion in optical fibers is divided into material dispersion, waveguide dispersion, and modal dispersion. Material dispersion is the dispersion that arises directly from the wavelength due to the response of the material to electromagnetic waves [25] which can generally be formulated as follows:

$$D_m = -\frac{\lambda}{c}\frac{d^2n}{d\lambda^2} \tag{1}$$

The dispersion of the wave combiner is influenced by certain fiber optic geometry which is a modification of the differential propagation time. The refractive index of the core and cladding is different for certain wavelengths. This dispersion depends on the speed of the signal group as written in the following equation [25]:

$$D_W = -\left[\frac{n_1-n_2}{\lambda c}\right]\frac{Vd^2(Vb)}{dV^2} \tag{2}$$

Modal dispersion only occurs in multi-mode optical fibers. This occurs because the rays entering the core follow different paths so that they reach the end of the fiber at different times. Mode is a description of physical and mathematical concepts for the propagation of electromagnetic waves through a medium and becomes a medium for rays to travel through fibers [25].

This research was carried out to minimize dispersion in pulse broadening by modifying the number of layers in the optical fiber from 2 to 7 layers including the sheath. The fiber optic design was simulated with the help of OptiFiber software with a center wavelength of 1.55 μm.

2. RESEARCH METHODS

Simulation and design using OptiFiber with a variety of layers on single-mode optical fiber from 2, 3, 4, 5, 6, and 7 as shown in Figure 1. The following layers on the fiber are as in Table 1. The core size for all layers is the same, namely 3 μm, while the cladding has a size of 20 μm, while the layer size variations for *n* = 3 have a size of 7 μm, *n* = 4 has a size of 3.5 μm, *n* = 5 has a size of 2.333 μm, *n* = 6 has a size of 1.75 μm, *n* = 7 has a size 1.4 μm with the refractive index of each layer as in Table 2.

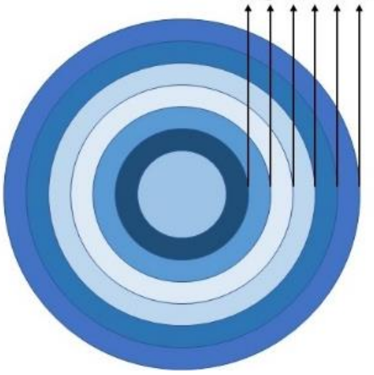


Figure 1. Illustration of optical fiber layers.

Table 1. Optical fiber layers.

Layer	Core	Cladding
2	1	1
3	2	1
4	3	1
5	4	1
6	5	1
7	6	1

Table 2. refractive index of each layer.

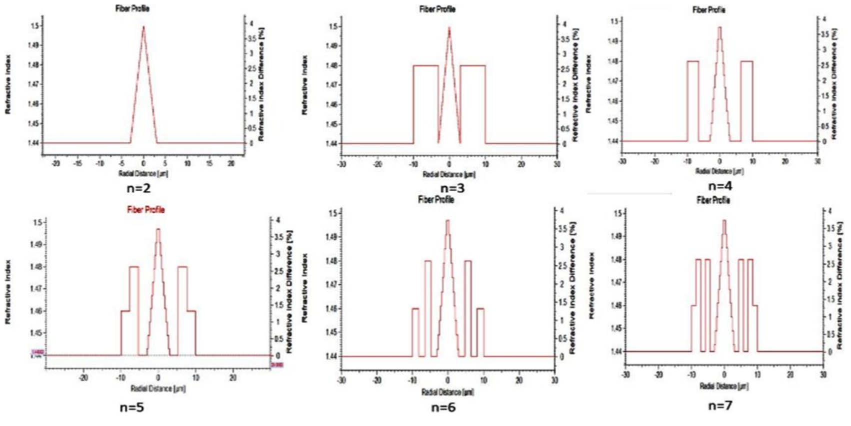
n	Core	Layer	Cladding
2	1.5 – 1.44	-	1.44
		1.48	
		1.44	
3	1.5 – 1.44	1.48	1.44
4	1.5 – 1.44	1.44	1.44
		1.48	
5	1.5 – 1.44	1.46	1.44
		1.44	
		1.48	
6	1.5 – 1.44	1.44	1.44
		1.46	
		1.44	
		1.48	
7	1.5 – 1.44	1.44	1.44
		1.48	
		1.46	

After defining the layer width and refractive index of each core and cladding, use OptiFiber to design and simulate each n layer. The data obtained from OptiFiber will be processed using Excel to determine the output graph of the relationship between zero dispersion for each layer, delay group, and effective area. OptiFiber is given a wavelength range of 1.2 μm and 1.6 μm to find the wavelength with zero dispersion at 1.55 μm.

3. RESULTS AND DISCUSSIONS

3.1. Fiber Optic Profile Design

The profile of each layer can be seen as in Figure 2 with a core width of 10 μm divided by n layers, each cladding 20 μm. The refractive index profile states the distribution of the refractive index in the core and cladding, the refractive index of the cladding is constant for all layers, namely 1.44.



n=2 n=3 n=4

n=5 n=6 n=7

Figure 2. Refractive index profile of *n* layers.

3.2. Delay Group Profile

Delay group profile is an important parameter in fiber optics, especially for modulated signals [8]. The delay group curve for each n layer can be seen in Figure 3. In Figure 3 each delay group of *n* layers has different characteristics, *n* = 2 experienced a decrease in group delay per unit wavelength, *n* = 3 experienced an increase in group delay, *n* = 4 experienced an increase in the delay group, *n* = 5 decreased the delay group, *n* = 6 decreased the delay group and *n* = 7 experienced a decrease in the delay group. Each delay group's decrease and increase varied, but the one that experienced the highest decrease was *n* = 7, while the increase in delay groups *n* = 3 and *n* = 4 was almost the same.

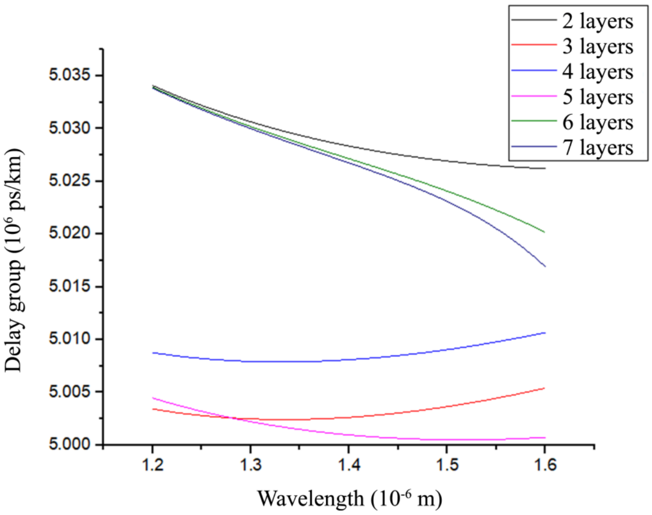


Figure 3. Curve of the effect of delay group on the wavelength of n layers of optical fiber.

Each n layer in the simulation has its own characteristics. It can be seen from the graph in Figure 4 that only 2, 3, 4, and 5 layer optical fibers go through zero dispersion while 6 and 7 layer optical fibers do not go through zero dispersion. However, optical fiber experiences zero dispersion at a wavelength of 1.55 μm. Zero dispersion is associated with a wavelength of 1.55 μm because this wavelength is suitable for SMF with low attenuation.

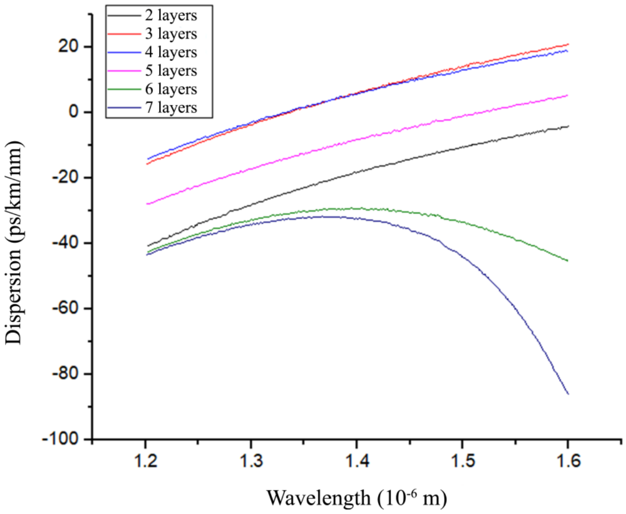


Figure 4. Dispersion curve of n layers for each wavelength.

It was found that the effective area and effective linear of the mode field diameter (MFD) (see Table 3) with layer *n* = 3 had the highest values, namely 17.1144 μm and 230.0454 μm^2 respectively, while the lowest values were in layer *n* = 6 with respectively 3.8 μm and 11.3414 μm^2. MFD states that the area through which light passes, not only passes through the core, but the light experiences expansion to some of the cladding of the area through which light passes, which is called the MFD.

Table 3. Effective area and MFD for several *n* layers.

n	Wavelength (μm)	Effective MFD (μm)	Effective area (μm^2)
2	1.55	3.7812	11.2292
3	1.55	17.1144	230.0454
4	1.55	15.1914	181.252
5	1.55	13.3936	140.8922
6	1.55	3.8	11.3414
7	1.55	3.875	11.7925

4. CONCLUSION

A single mode fiber design has been successfully created with variations of 2 to 7 layers of core while the sheath has the same size, obtained for layers that meet zero dispersion at a wavelength of 1.55 μm, while the effective area or diameter of the signal through the core and sheath is the highest in the design layer. 3 layers with values of 17.1144 μm and 230.0454 μm^2 respectively which can provide good performance in SMF while the lowest value is in the six layer design with values of 3.8 μm and 11.3414 μm^2 respectively besides that the effective area is directly proportional to the MFD.

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