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# Comparative Investigation of Graded Index Optical Fiber Characteristics by Using Different Materials

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***Abstract- Influence of different materials on graded index optical fiber systems was studied, these materials(channel 1 has a core made from PMMA+ and cladding of carbon fluorine polymer,channel 2has a core made from Polystyrene PS++ and cladding of Polymer PMMA+,the third channel has the core made from Silica with cladding of Silicon resin), were examined for their effect on quality factor ,total output power (dBm) and intermodal dispersion at the receiver.All the channels operated at the same optical transmitted with non return-to-zero (NRZ).Performance study was done for variable lengths of fiber 1, 2, 3, 4 km for these different material channelsby simulating a model of communication system.Optisystem software has been used for this simulation.Results reveal the ability of improving the graded index fiber characteristics by using these materials and theoptimum effect concluded at(20dBm) input powerby using the third channel material i.e.the quality factor and total output power were increased to reach(374.2 ) and (-9.073 dBm) respectively and intermodal dispersion decreased to reach(11.822 ns/km).***

***Keywords: Graded index fiber,Polymer Optical Fiber, Intermodal dispersion.***

## I.INTRODUCTION

In 1966, introduced the first type of Polymer Optical Fiber (POF) product named Crofon with PMMA core to the market. The development activities in the past 40 years were aimed at removing some major disadvantages of POF.Multimode polymer optical waveguides have been expected to be high performance data communication devices for short range interconnections, ranging from one board-to- another board [1,2].POFs have the same geometry as silica optical fibers, with a core, cladding and sometimes a jacket. A variety of optical polymers are used in the fabrication of POFs, including polymethyl-methacrylate (PMMA) [3].Large-core, low-cost polymer optical fiber (POF) provides several advantages [4], [5]. The large core of the POF allows the use of inexpensive injection-molded plastic connectors, which makes it possible to dramatically decrease the cost of interface devices such as network interface card and installation cost.The important characteristic of optical fiber is the bandwidth. This is limited by the signal dispersion within the fiber, which determines the number of bits of information transmitted in a given time period. Therefore once the attenuation was reduced to acceptable levels attention was directed towards the dispersive properties of fibers [6]. Intermodal dispersion is one of these properties which acts as a critical factor in optical fiber data transmission. The light is able to take many different paths or "modes" as it travels within the multimode fiber. The distance traveled by light in each mode is different from the distance traveled in other modes.

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This paper was studiedthe performance analysis of agraded index multimode fiber for three channel with different materials to test minimum of bit error rate, maximum quality factor and total output power for transmission system.The system transmits the data from 1 -4 km with variable input power from 0-30dBm. It was shown that the spectrum began to be shaped by eye diagram Analyzer, was used for the performance analysis. Optisystem software has been used for this simulation.

## II.BACKGROUND THEORY

Optical communication system using Plastic Optical Fibers(POF) have not reached their potential for a number of reasons, the rapid growth of glass optical fiber technology and because plastic optical fibers have been relegated low speed, short distance applications.Graded index plastic optical fiber is in great demand in customer premises to deliver high-speedservices due to its high bandwidth, single-mode POF, optical amplification in plastic fibers, there are new POF materials with low loss and higher power and faster sourceshave been developed.[7].

### *2.1 Materials used in the fabrication of optical fibers*

For fabrication of optical fibersthere are a numberof materials will be used. To satisfies a certain conditions, all these materials are selectedsuch as ,it should have good optical transmission quality for efficient optical transmission ,the core and the claddingmaterials should have slightly different refractive indices to satisfy total internal reflection.[7].

### *2.1.1Materials used for POF PMMA*

The material most frequently used for the fabrication of POF is the thermoplastics PMMA (Polymethylmethacrylate). From the beginning of 80's the available POF were found to have an attenuation of around 150dB/km. PMMA-SI-POF has a theoretical minimum attenuation of 106dB/km at 650nm [8],[9]which is due to the Rayleighscattering and absorption of C-H bonds. In addition there are the losses resulting from waveguide structure, particularly when taking into account the attenuation resulting from cladding.The bond structure of PMMA is as shown in the figure 1.

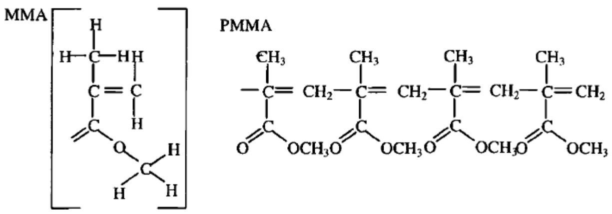


Figure 1: Structure of PMMA

### *2.1.2Polystyrene polymer flbers*

Polystyrene is another suitable candidate for making POFs. Its molecular structure is as shown in the figure 2. The initial fibers had an attenuation of over 1,000dBIkm, later it was possible to reduce this to 114dB/km at 670 nm. The NA of these fibers which can be used at temperatures up to 70 C, a little higher than that for standard PMMA-POF. The refractive index ofPS is n=1.59 so that it is possible to use PMMA as the cladding material[10].

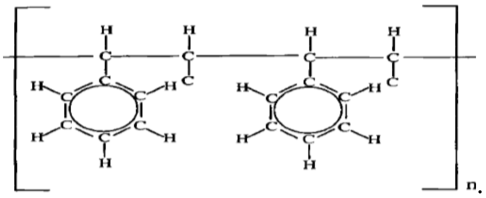

**Figure 2: Structure of Polystyrene**

***2.1.3Silica glass fibers***

They are made by fusing metal oxide, sulphides and selenides. Oxide glasses are mostly used for making optically transparent glasses. The most common is silica (Si02) , which has refractive index of 1.458 at 850nm. To produce two similar materials that have slightly different refractive indices for core and cladding, various oxides are added to silica.Silicon dioxide (silica) is one of the most commonly encountered substances in both daily life and in electronics manufacturing. Crystalline silicon dioxide (in several forms: quartz, cristobalite, tridymite) is an important constituent of a great many minerals and gemstones, both in pure form and mixed with related oxides. Beach sand is mostly silica. The working of silica into glass (usually by the addition of natron -- sodium oxide -- to lower the melting point) has been known since antiquity, with polished glass lenses in eyeglasses and optical instruments dating back more than 5 centuries.

The whole of planar electronics processing and the modern IC industry has been made possible by the unique properties of silicon dioxide: the only native oxide of a common semiconductor which is stable in water and at elevated temperatures, an excellent electrical insulator, a mask to common diffusing species, and capable of forming a nearly perfect electrical interface with its substrate. Deposited silicon dioxide, almost always by CVD approaches, is almost as old as thermal growth on the substrate, and has been employed in various ways in IC fabrication due to its familiarity, versatility, and reliability. SiO2 is formed by strong, directional covalent bonds, and has a well-defined local structure: four oxygen atoms are arrayed at the corners of a tetrahedron around a central silicon atom:

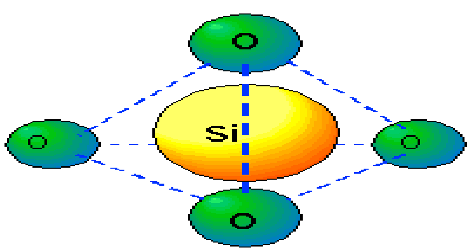


**Figure 3: Structure of Silica**

The result of this flexibility in the bridge bonds is that SiO2, while it has many different possible crystalline structures, can very easily form amorphous materials (i.e. materials with no long-range order). Essentially all deposited and thermally grown oxides in semiconductor processing are amorphous. Unlike e.g. amorphous silicon, amorphous silicon dioxide will not crystallize upon annealing at normal temperatures. ("Devitrification" -- that is, crystallization -- of quartz furnace tubes used for high-temperature oxidation is sometimes observed after thousands of hours of use at temperatures exceeding 1200 C.) The amorphous structure is tends to be very "open": even in thermally-grown oxides, channels exist through which small positive ions such as Na+ and K+ can readily migrate. These ions can move under the influence of electric fields within the gate oxides of MOS transistors, causing shifts in the voltage at which the transistor turns on ("threshold shifts"). Exclusion of such ions is imperative for reliable operation of MOS transistors and integrated circuits.

Some important properties of pure SiO2:

| | |
|---|---|
| density | 2.0-2.3 gm/cm3 |
| electrical conductivity | varies widely |
| breakdown field | >1E7 V/cm in thermal oxides; can be as low as 1E6 V/cm in CVd oxides |
| thermal conductivity | 0.01 W/cm K (bulk) |
| thermal diffusivity | 0.009 cm2/sec (bulk) |
| coefficient of thermal expansion | 0.5 ppm/ K [note Si thermal exp 2.3 ppm/K] |
| refractive index | 1.46 [thermal oxide] |
| dielectric constant | 3.9 [thermal oxide]; CVD oxides vary widely depending on H |

It is important to note that many of the properties of SiO2 show wide variability, because of the flexibility of the structure mentioned above.

2.2 Dispersion

The duration of the pulse propagating in an optical fiber increases with distance of propagation. The pulse of light is composed of wavelengths; the propagation velocity is not the same for all wavelengths. This phenomenon is called dispersion [11].The bandwidth of the systemaffects with dispersion, then maintaining low dispersion is of equal importance for ensuring increased system information capacity [12].In order to appreciate the reasons for different amounts of pulse broadening within the various types of optical fiber, it is necessary to consider the dispersive mechanisms involved. These include intermodal dispersion.

2.2.1 Intermodal Dispersion

Intermodal dispersion produces from the propagation delay differences between modes within a multimode fiber (MMF). As the different modes which constitute a pulse in multimode fiber travel along the channel at different group velocities, the pulse width at the output is dependent upon the transmission times of slowest and fastest modes.

For step index and parabolic-index MMF, the modal impulse response turns out to be a square pulse that is, when an impulse excitation is launched into the fiber, the propagating modes are distributed evenly between the fastest mode and the slowest mode. Intermodal dispersion does not occur in single-mode fibers, but is a significant effect in


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multimode fibers .Figure 4 is a schematic diagram illustrating the pulse broadening due to intermodal dispersion in three different optical fiber [11],[13].

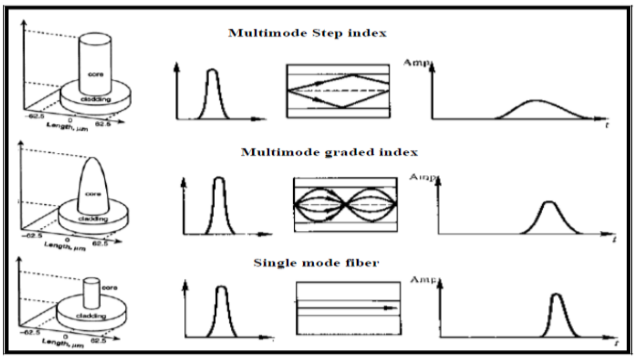


Figure4. Schematic diagram showing a multimode step index fiber, multimode graded index and single mode step index fiber, and the pulse broadening due to intermodal dispersion in each fiber type [11].

(A)Multimode Step Index Fiber

Multipath dispersion can be understood by referring to Figure5, where different rays travel along paths of different lengths. These rays disperse in time at the output end of the fiber even if they were coincident at the input end and traveled at the same speed inside the fiber [14].

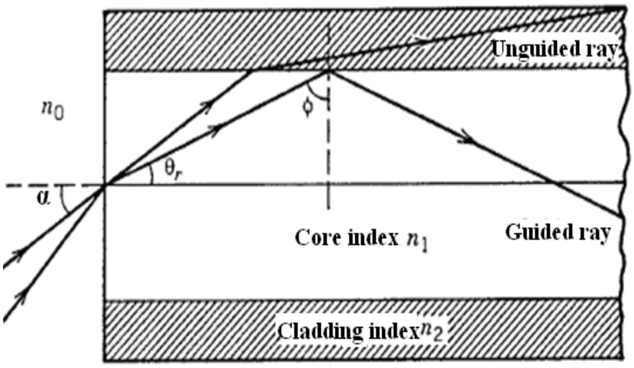


Figure5. The paths taken by the axial ray and an extreme meridional ray in a perfect multimode step index [14].

All the both rays axial ray and an extreme meridional ray are traveling at the same velocity within the constant refractive index fiber core then the delay difference is directly related to their respective path lengths within the fiber. The time taken for the axial ray to travel along a fiber of length L gives the minimum delay time TMin.

$$T_{Min} = \frac{Ln_1}{c} - \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

where $n_1$is the refractive index of the core and c is the velocity of light in a vacuum .

The extreme meridional ray exhibits the maximum delay time$T_{Max}$.

$$T_{Max} = \frac{Ln_1}{c\cos\theta} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

Using Snell's law of refraction at the core-cladding interface following equation (3)

$$\sin\emptyset_c = \frac{n_2}{n_1} = \cos\theta \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

where $n_2$ is the refractive index of the cladding. Further more, substituting into equation (2) for cos θ gives:

$$T_{Max} = \frac{Ln_1^2}{cn_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4)$$

The delay difference δTs between the extreme meridional ray and the axial ray may be obtained by subtracting equation (1):

$$\delta T_s = T_{Max} - T_{Min} = \frac{Ln_1^2}{cn_2} - \frac{Ln_1}{c} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5)$$

$$\delta T_s = \frac{Ln_1^2}{cn_2}\left(\frac{n_1 - n_2}{n_1}\right) \cong \frac{Ln_1^2\Delta}{cn_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(6)$$

where Δ is the relative refractive index difference. However, when Δ<<1, the relative refractive index difference may also be given approximately by:

$$\Delta = \frac{n_1 - n_2}{n_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(7)$$

Then rearranging equation (6):

$$\delta T_s = \frac{Ln_1}{c}\frac{n_1 - n_2}{n_1} \approx \frac{L\,n_1\,\Delta}{c} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(8)$$

Also substituting for Δ:

$$\delta T_s = \frac{L\,(NA)^2\,\Delta}{2n_1c} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(9)$$

Equation (10) below shows the rms pulse broadening at the fiber output due to intermodal dispersion for multimode step index fiber σs [11],[ 14].

$$\sigma_S = \frac{L\,n_1\,\Delta}{2\sqrt{3}\,c} = \frac{L\,(NA)^2}{4\sqrt{3}n_1c} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...(10)$$

(B) Multimode Graded Index Fibers

The refractive index of the core in graded-index fibers is not constant but decreases gradually from its maximum value $n_1$at the core center to its minimum value $n_2$at the core–cladding interface [15].Intermodal dispersion in multimode fibers is minimized with the used graded index fiber .Hence multimode graded index shows substantial bandwidth improvement over multimode step index fibers. The reason for improvement performance for graded index fiber may be observed by considering the ray diagram for graded index fiber shown in Figure (6) [11].

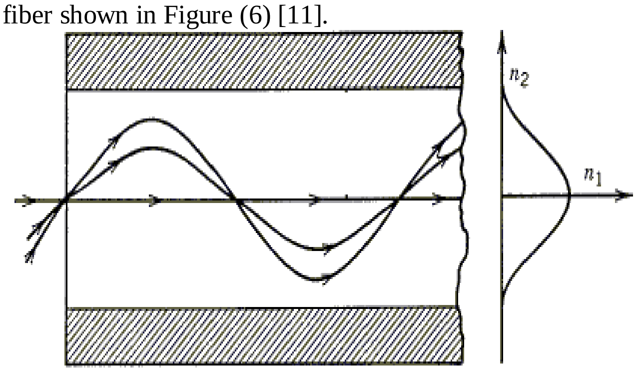


Figure 6. Ray trajectories in a graded-index fiber [14].

$$\delta T_g = \frac{L\,n_1\Delta^2}{8\,c} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(11)$$

The rms pulse broadening of a near parabolic index profile graded index fiber σgis reduced compared to the similar broadening for the corresponding step index fiber σs[11].

$$\sigma_g = \frac{L\,n_1\Delta^2}{20\sqrt{3}\,c} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(12)$$

The optisystem

## III. SYSTEMDESCRIPTION

software is very important will be used to model and simulate fiber optic system.The circuit diagram which generates and transmits the power is shown in Figure7. The transmitted of optical system consist of Pseudo –Random Bit used to generate sequence random of bits (0 or 1)., NRZ pulse generator has an advantage on controlling bandwidth. This is due to the characteristic of the


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generator that the returning signals to zero between bits. Pseudo-random bit sequence generator is used to scramble data signal in terms of bit rates[16], Mach Zender-Modulator has two inputs and one output. Then the input signal is modulated with semiconductor laser that is represented by spatial Continuous Wave (CW) laser through Mach- Zehnder modulator. The spatial Continues laser diode (CW) to generate optical signals supplies input signal with 850 nm wavelength and input power variable from 0-30dBm which is externally modulated.The pulses are launched into the fork 1xN which distributed power into three branch .

The next mount is a compound unit. Consist of graded index multimode fiber,the first channel is material 1, has the core made from PMMA+ with refractive index is 1.4 and cladding Carbon fluorine polymer with refractive index 1.39 .The second material 2,has the core made from PolystyrenePS$_+^+$ with refractive index is 1.59 and cladding from Polymer (PMMA+) with refractive index 1.49 .The third material,has the core made from Silica with refractive index 1.46 and cladding from Silicon resin with refractive index is 1.4,and all channels has attenuation of 2.61 dB/km.The final group of components consists of a compound mount,fiber amplifier (EDFA).Optical amplification is required to overcome the fiber loss and also to amplify the signal before receiving by Photo detector PIN at the receiver partPhotodetector Diode Positive Intrinsic Negative (PIN) to translate the optical signal into an electrical signal.One photon yields one electron [17], and eye diagramfor monitoring output signals after each component.

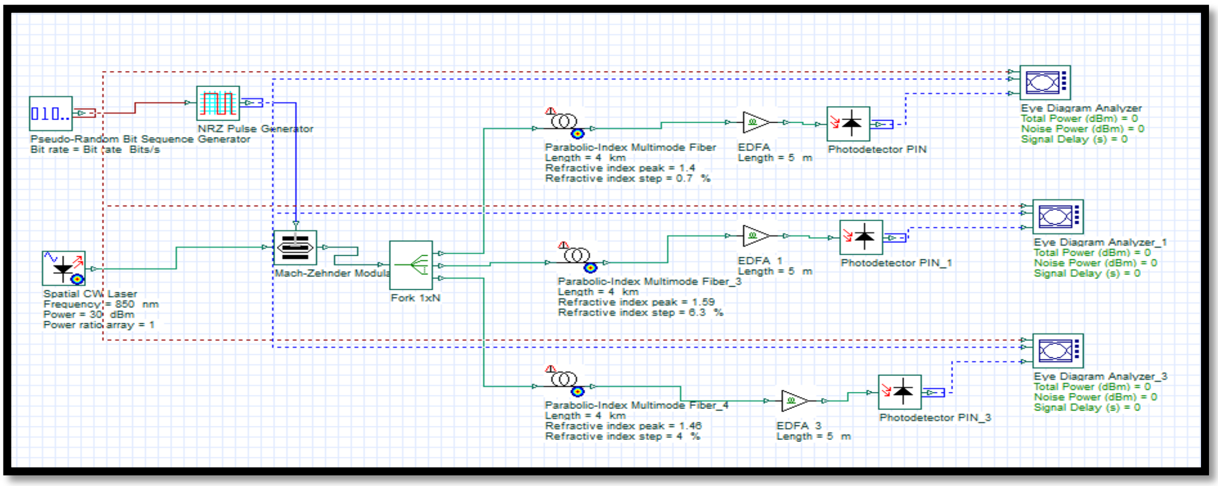
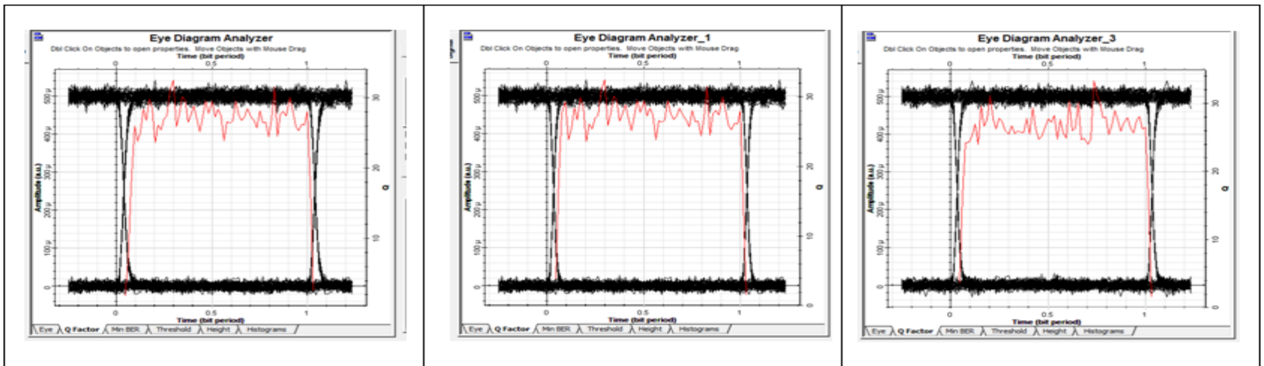


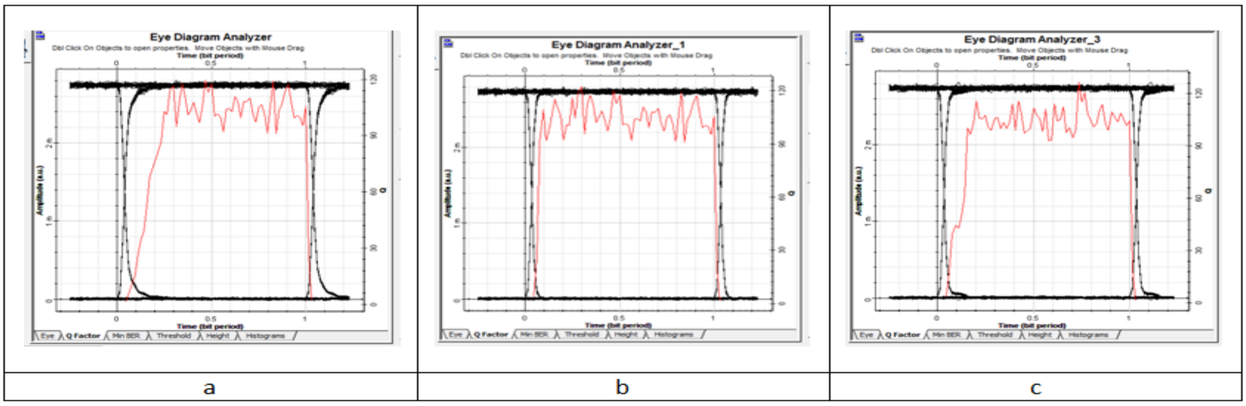

Figure 7 : The designed model of simulated system with Optisystem software

The simulation and optimization of the design is done by OptiSystem 7 simulation software. The eye diagrams and results of maximum Q. factor, intermodal dispersionand output power at receiver are shows from Figure 8 until Figure11, by using three different material of graded index fiber with variable length of optical communication and different input power starting from 0 dBm to 30 dBm .The related graphs are also plotted as shown in Figure 12 , 13 and 14.




| a | b | c |
|---|---|---|

Figure 8: Graded index multimode fiber of length 1km (a)Eye diagram of material 1(b) Eye diagram of material 2.(c) Eye diagram of material 3.




.Figure9:Graded index multimode fiber oflength 2km(a) Eye diagram of material 1.(b) Eye diagram of material 2.(c) Eye diagramof material 3.

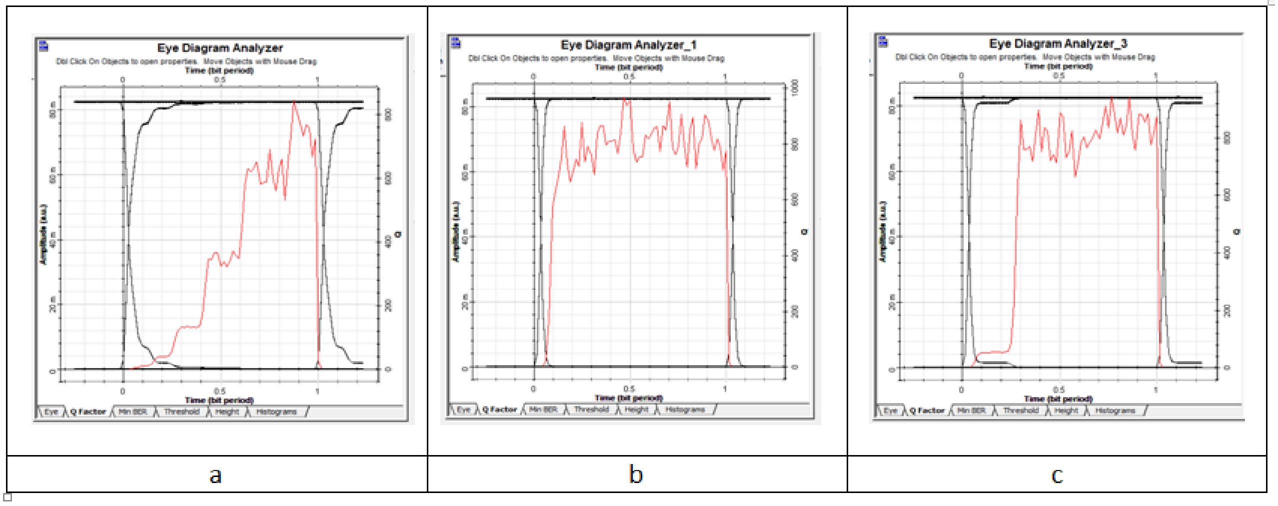



Figure10: Graded index multimode fiber oflength 3km. (a)Eye diagram of material 1.(b) Eye diagram of material 2.(c)Eye diagramof material 3

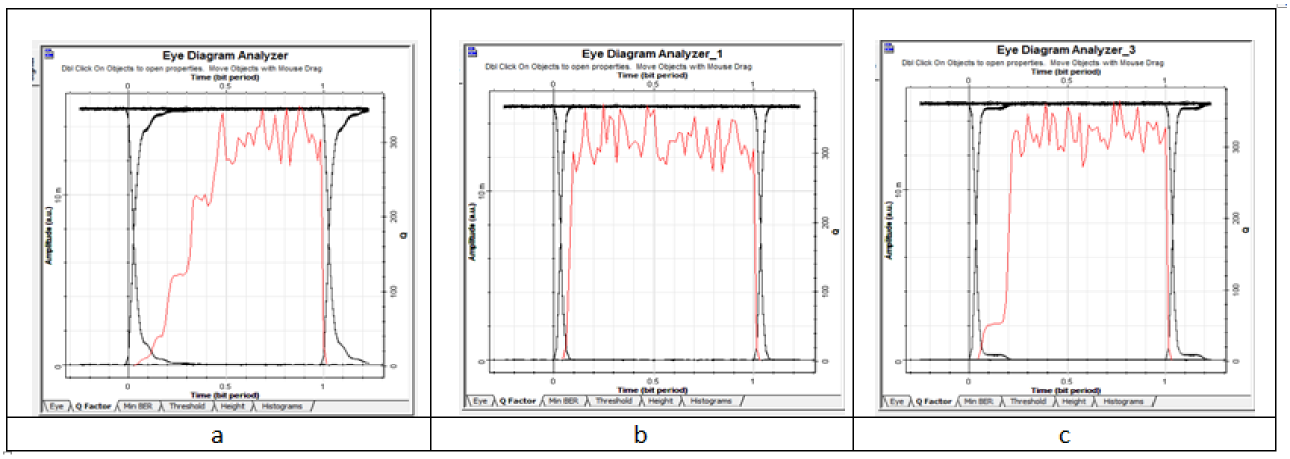



Figure11.Graded index multimode fiber oflength 4km. (a)Eye diagram of material 1. (b) Eye diagram of material 2.(c)Eye diagramof material 3

The effect of quality factor, intermodal dispersion and total power with respect to variable input power and distance of the graded index multimode optical fiber for use the three difference material. The simulation parameters are obtained listed in Table 1.

Table 1 Effect of Maximum.quality.Factor with respect to variable input power of difference material type for graded index multimode fiber.

| Input power (dBm) | Max. Q.Factor material 1 | Max. Q.Factor Material 2 | Max. Q.Factor material 3 |
|---|---|---|---|
| 0 | 32.46 | 32.41 | 35.27 |
| 10 | 119.424 | 122.231 | 136.5 |
| 20 | 348.2 | 370.34 | 374.2 |
| 30 | 844.13 | 948.95 | 982.65 |

Table 2 Effect of Intermodal dispersion with respect to variable input power of difference material type for graded index multimode fiber.

| Input power (dBm) | Intermodal dispersion material 1 (ns/km) | Intermodal dispersion material 2 (ns/km) | Intermodal dispersion material 3 (ns/km) |
|---|---|---|---|
| 0 | 11.82 | 9.823 | 3.94 |
| 10 | 23.64 | 19.646 | 7.88 |
| 20 | 35.46 | 29.47 | 11.822 |
| 30 | 47.28 | 39.3 | 15.763 |

Table 3 Effect oftotal power with respect to variablelength of graded index multimode fiber for three difference material.

| Length of fiber (km) | Total power of material 1 (dBm) | Total power of material 2 (dBm) | Total power of material 3 (dBm) |
|---|---|---|---|
| 1 | -39.28 | -39.278 | -39.2603 |
| 2 | -24.518 | -24.5017 | -24.3084 |
| 3 | -9.776 | -9.772 | -9.073 |
| 4 | 5 | 5.026 | 7.57 |

It is observed in Figure 12 that Maximum Q Factor calculated with change the input power whichindicated from Table 1.

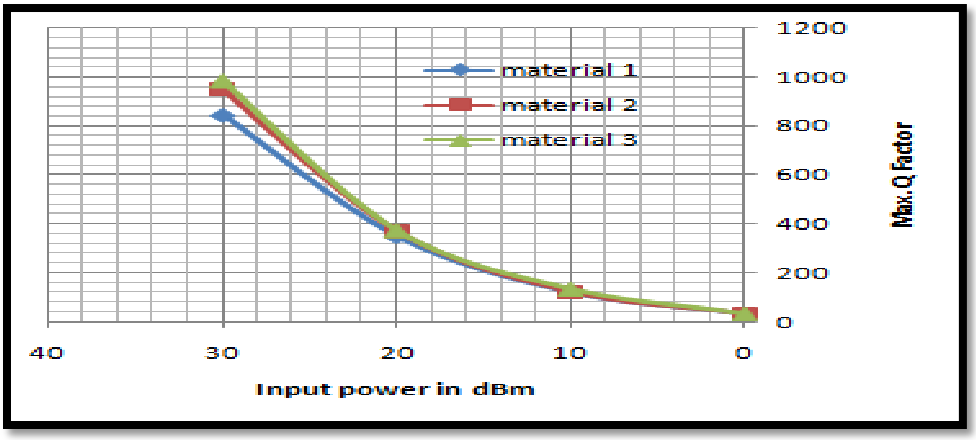



Figure12: Maximum quality factor figure versus input power in dBm

Figure 13 it is observed that intermodal dispersion calculated with change the length of optical fiber whichindicated from Table 2

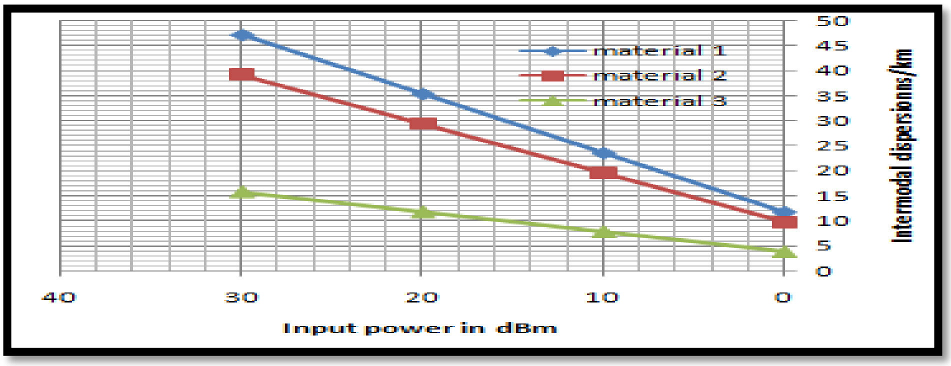



Figure13: Intermodal dispersionfigure versus input power in dBm.

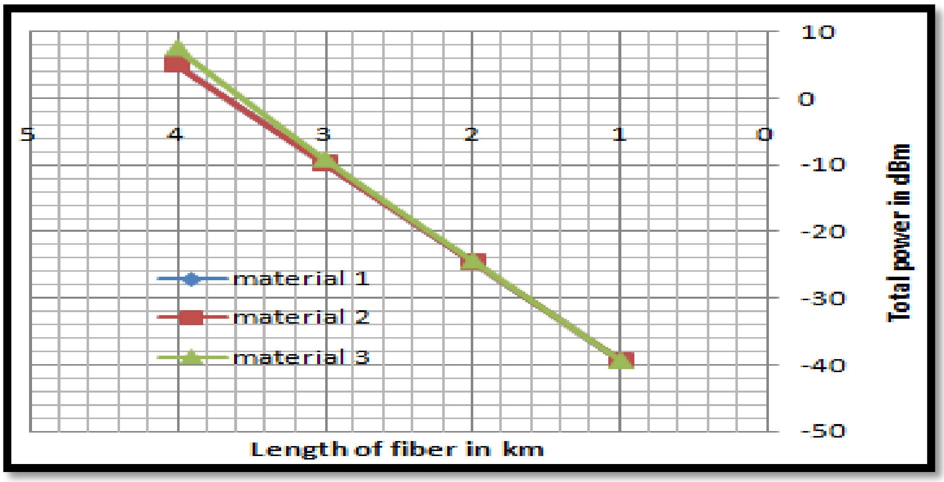



Figure14: Total output power figure versus length of graded index fiber in km.

In this work, implementation and performance analysis of aintermodal dispersion, maximum quality factor andtotal output power for transmission system. From this design, the graded index multimode optical fiber transmission system can be consist of plastic core fiber and silica core fiber coated with polymer acts as to improvement maximum quality factor, intermodal dispersion and total power . As seen from above results which abstract from Tables 1 into Tables 3,when compare the result for use graded index fiber show that all reading atinput power 20dBm through used three types material, then the maximum quality factor with material 1is 348.2,intermodal dispersion35.46ns/km andtotal output power is -9.776 dBm. For material 2the maximum quality factor is370.34,intermodal dispersion29.47 ns/kmandtotal output power is-9.776 dBm.At material3the maximum quality factoris374.2,intermodal dispersion11.822 ns/km and total output power is -9.073 dBm.

Figure12, shows that with increasing input power caused themaximum quality factor increased exponentially, while in the Figure 13, intermodal dispersion increase linearly as increasinginput power. At the end total output powerdecreased linear with increased length of the fiber.

## IV CONCLUSION

In this paper, the design study to improve intermodal dispersion,total output power and quality factorof transmission system for various input power with various length of fiber has been studied. The results are valuable for improving system performance by using graded index multimode fiber with three different materialstypes.As seen from above results,in optical fiber withmaterial 3give the best results i.e. reduced the value of intermodal dispersion and increased the values of total output power and the quality factor when compared withmaterial 1andmaterial 2.

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