Design, simulation, performance analysis and optimization process of MMGRIN fiber with RI distribution

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Abstract- This paper assembles the easy way to design graded index fiber using refractive index (RI) profile/distribution, simulation of the input parameters for having output characteristics using OptiFiber simulator and performance analysis by observing the output. Here multilayer GRIN fiber design will be used by creating several layers so that optimization process will be easy to evaluate. Also mode base performance analysis will be done so that the analysis can help a person to understand the criteria's that should follow in designing MMGRIN fiber and factors which can affect fiber performance.

Keyword- GRIN fiber; multilayer fiber; multimode; parabolic profile; exponential profile

I. INTRODUCTION

In graded index fiber the refractive index gradually decreases from center to surface of the core. The following figure shows the mechanism for graded index fiber. There we can see that light direction changes with the change of position. This is the special feature of the Graded Index fiber (GRIN fiber) of variable refractive index difference along the core to cladding [1].

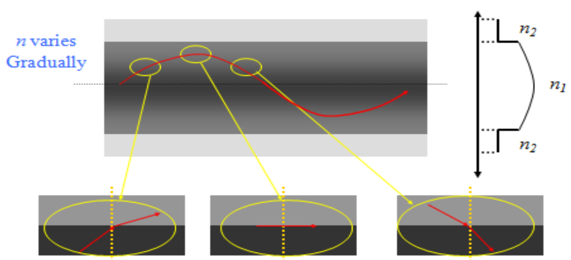

Figure 1. Light passing procedure of GRIN fiber with refractive index variation. And light direction through fiber in segment view.

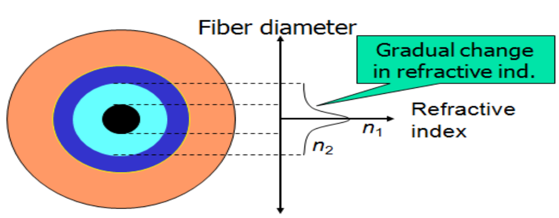

Figure 2. Refractive index (RI) characteristic of GRIN fiber.

The specific MMGRIN fiber parameter are-

Core diameter	: 30 ~ 100 μm
Cladding diameter	: 100 ~ 150
Buffer jacket diameter	: 250 ~ 1000
NA	: 0.2 ~ 0.3
αdB	:2-10 dB/km(0.85 μm)
αdB	:0.4 dB/km(1.3 μm)
αdB	:0.25 dB/km(1.55 μm)
Bandwidth	: 300MHz-km ~ 3 GHz-KM
Applications	: Medium-haul, medium to high bandwidth applications. [1]

II. THEORY

OptiFiber calculates effective Mode Field Diameter defined as [2],

$d_{eff} = \frac{2\sqrt{2}E_i^2 rdr}{\sqrt{[\int E_i^2 rdr]}}$ *μm..... (1)*, Where E(r) is the optical mode field distribution. It can be expressed as a function of Effective mode field area.

$d_{eff} = \frac{2}{\sqrt{\pi}}\sqrt{A_{eff}}$ *μm..... (2)*, where A_{eff} = Effective mode field area and expressed as - $A_{eff} = \frac{\left[\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}|E(x,y)|^2dxdy\right]^2}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}|E(x,y)|^4dxdy}$ *μm* ^{2}...... *(3)*, Where E(x, y) is the optical mode field distribution.

The cut-off wavelength for any mode is defined as the maximum wavelength at which that mode will propagate. OptiFiber currently implements two different approaches for finding the [3]:

A “Theoretical” cut-off value: This is the wavelength, above which the given mode cannot propagate,

An “Estimated ITU-T” cut-off value: These values are obtained by emulating the actual experimental cut-off measurements, as described in the ITU-T / TIA / EIA recommendations.

In this paper cut-off wavelength are taken at LP11 mode, because at LP11 mode fiber optic characteristic is more accurate with better transmission and reception from another mode.

Total dispersion defined as [1], $D_{total} = -\frac{z}{c}\lambda\frac{d^2N_{eff}}{d\lambda^2}\ \mu m$ ... (4), which means broadening of the transmitting signal that means how much the signal distorted from the actual signal. A Dispersion characteristic is the main problem of transmitting signal or data through multimode but in single mode fiber it has less effect of performance.

Microbending loss means loss for bending the fiber horizontally in transmission set up. An approximate expression for Microbending loss is [4] - $\alpha_{micro} = A(kn_1d_n)^2\,(kn_1d_n)^{2p}$ dB/Km..... (5), Where A is a constant, d_n is the near field diameter and its equation is [2] ,

$d_n(\mu m) = 2\sqrt{2}\sqrt{\left(\frac{\int_0^\infty E^2(r)r^3\,dr}{\int_0^\infty E^2(r)r\,dr}\right)}$ .....(6), n_1 is the core refractive index of fiber, k is the free space wave number, and p is the exponent in the power law.

Another important feature of microbending loss is, sometime it introduces critical radius of curvature and it is intense in multimode fiber. Critical radius of curvature is the curvature of bending fiber at which data transmission hampered excessively and large loss occur [7].

III. DESIGN AND SIMULATION

In optifiber simulator, for designing graded index fiber we use multilayer to define core and cladding in profile designing dialog box. The core is graded in several layers to make the graded portion and the outer layer will be cladding. Graded index fiber used to modify the index of refraction gradually as written before so the performance can vary gradually not sharply [2].

A. Designing single mode graded index fiber

In designing of graded index fiber 3 regions are used for grading in core. The core region diameters are 1.5, 1.5, 1.5 and cladding is 58.35. First 3 regions profile are linear and 4th region is constant. Refractive index is varied in core (region 0 →2) from 1.446→1.444, 1.444→1.442, 1.442→1.44 and refractive index of region 3(cladding) is 1.44. Applying this input, fiber profile look like-

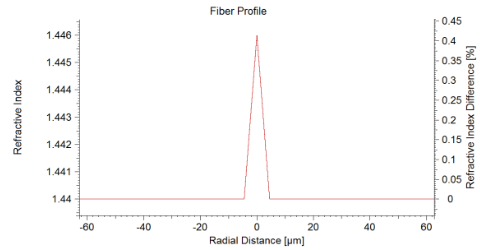

Figure 3. Fiber profile

After executing the inputs by selecting modes from the mode created in the profile which are available or real, the dispersion tab shows the dispersion with the information of zero dispersion wavelength and zero dispersion slope. The figure looks like below-

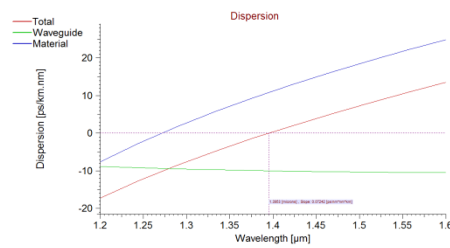

Figure 4. Dispersion

Where zero dispersion wavelength is found 1.3951µm and slope 0.07123(ps/ (nm2*km)). [5].

Another important feature is mode field characteristic. Here the figure below shows the information about far field, near field, effective mode field diameter and effective mode field area at a time. We can find the value at 1.3 or 1.55 microns by using graph tool. Among the parameters the effective mode field diameter is one of the most important because it gives a clear view about how much light is concentrating in the fiber or escaping from the fiber.

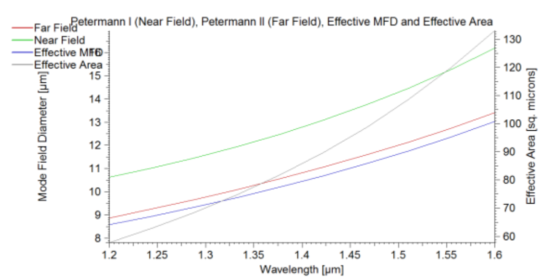

Figure 5. Effective mode field diameter

At 1.31µm Eff. MFD is 9.52934 and at 1.55µm it is 12.3106 [5]

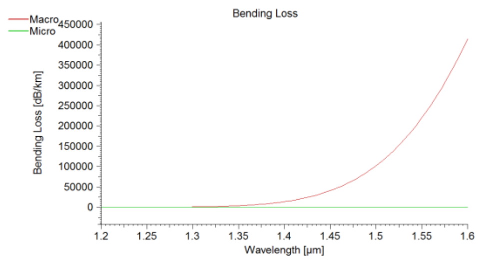

Figure 6. Bending loss

The figure above shows the bending loss including micro bending and macro bending, which is zero. Splice loss tab shows the splice loss. The losses found at 1.31µm and 1.55µm is listed later.

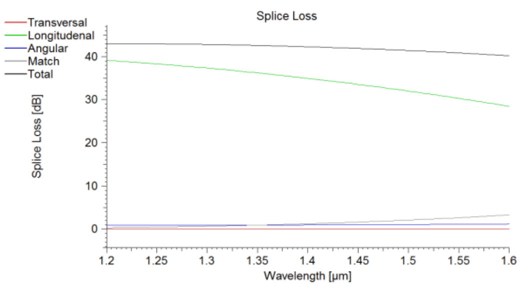

Figure 7. Splice loss

The figure 7 shows the splice losses of different features. From the total loss curve we can find out the loss at 1.3 and 1.55 microns. Splice needs at fiber when the fiber breaks or joining for repair.

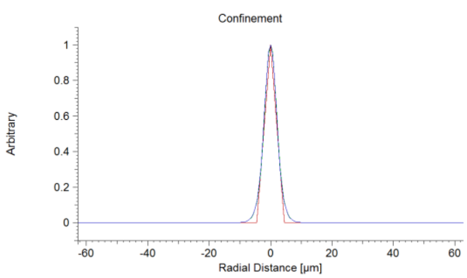

Figure 8. Confinement

We observe the confinement characteristics by changing core fiber profile. Except linear profile two other profiles (parabolic and exponential) are analyzed. The fiber profile and confinement both for parabolic and exponential profile exactly look like this-

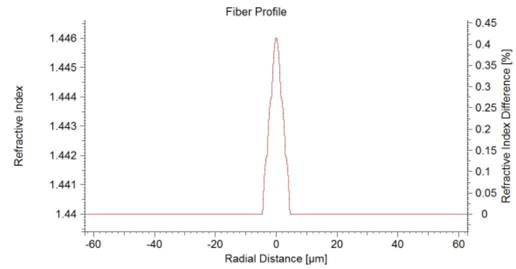

Figure 9. Parabolic profile

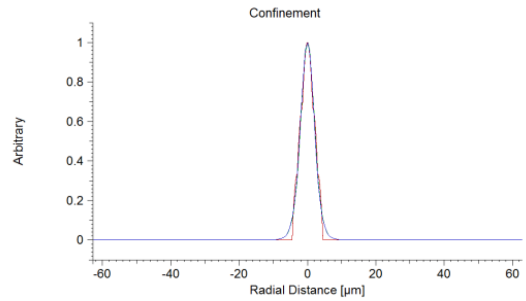

Figure 10. Confinement in parabolic profile

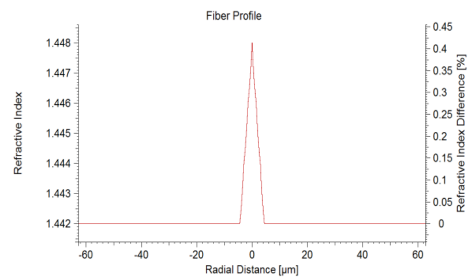

Figure 11. Exponential profile

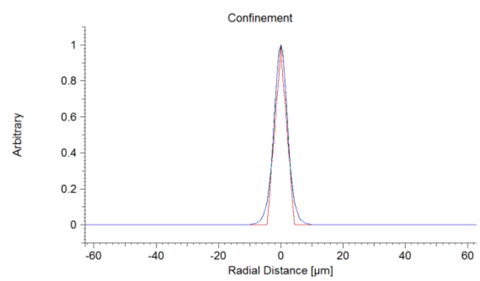

Figure 12. Confinement in exponential profile

B. Designing multimode graded index fiber

In designing multimode graded index fiber four regions are added where first 3 regions is core for grading and the fourth region is cladding region. For first 3 regions (region0, region1and region2) input wavelength is 1.3µm and diameters are 10, 10 and 10µm respectively. For cladding region diameter is 58.35 µm. Refractive index for region 0 to 3 are 1.448→1.446, 1.446→1.444, 1.444→1.442 and 1.442→1.44 respectively.

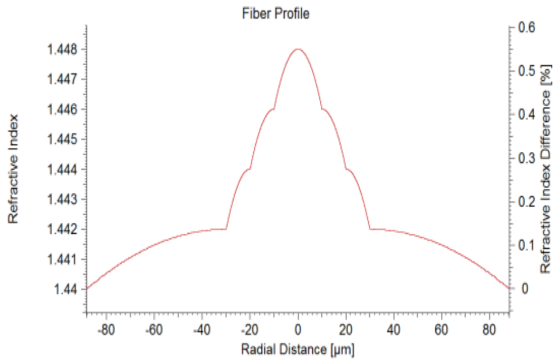

Figure 13. Parabolic profile

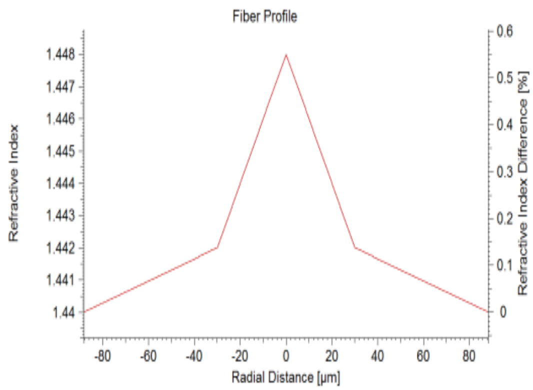

Figure 14. Linear profile

After calculation with selecting 14 modes (when the profile is parabolic) dispersion characteristics will be-

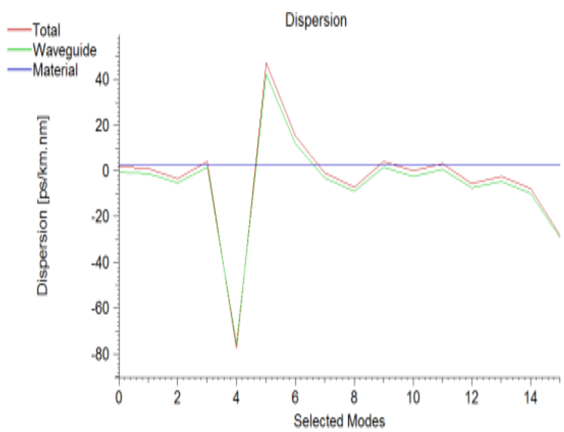

Figure 15. Dispersion for parabolic profile

For linear profile with 20 modes selected dispersion characteristic is shown below:

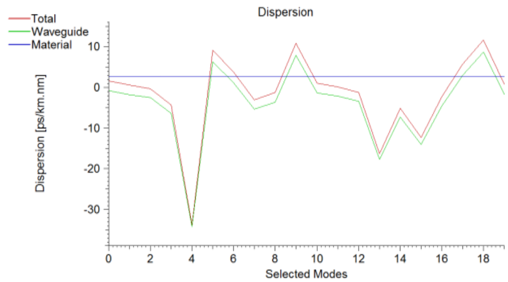

Figure 16. Dispersion for linear profile

For parabolic profile bending loss is below:

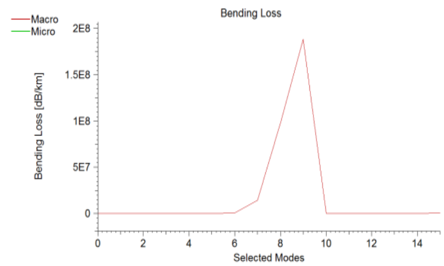

Figure 17. Bending loss in parabolic profile

For linear profile and with 20 modes selected bending loss is shown below:

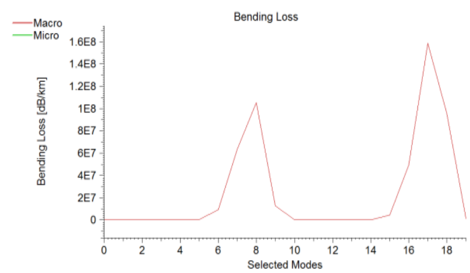

Figure 18. Bending loss in linear profile

Confinement of light in the fiber core selcting parabolic/linear profile is shown here below

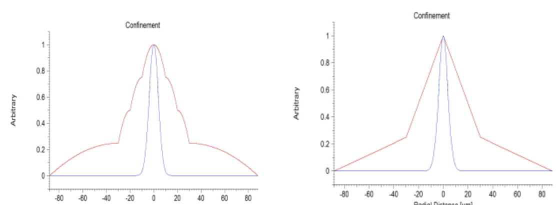

Figure 19. Confinement for Parabolic and liner profile accordingly

Here the blue colored line shows the confinement characteristics. This is visibly appropriate. It refers that in the top of the core segment the LP mode directed thorough center of the core [6].

IV. PERFORMANCE ANALYSIS

A. Analytical performance observation

TABLE 1: INPUT PARAMETER FOR DESIGNING GRADED INDEX FIBER

(*Wavelength was taken 1.3µm)

Input parameter of grades	Diameter	Refractive index(n)
Region 0	1.5	1.446 →1.444
Region 1	1.5	1.444 →1.442
Region 2	1.5	1.442 → 1.44
Region 3	58.35	1.44

TABLE 2: COMPARISON OF GRADED INDEX FIBER VARYING FIBER PROFILE

Characterized parameter	Liner profile	Parabolic profile	Exponential profile
Zero dispersion wavelength(µm)	1.3951	1.3846	1.399
Zero dispersion slope (ps/(nm2*km))	0.07123	0.08261	0.08046
Cutoff wavelength at LP11	0.7875	0.875	0.760937
Eff. MFD at 1.31 µm 1.55µm	9.52934 12.3106	9.11854 11.4107	9.77949 12.8870
Microbending at 1.31µm 1.55µm	0 0	0 0	0 0
Splice loss(dB) 1.31µm 1.55 µm	42.7665 40.8089	44.0243 42.7122	42.0566 39.6910

B. Graphical representation of the single mode graded index parameters:

While analyzing the single mode graded index parameters we determined the technological parameter referencing with respect to fiber core profile.

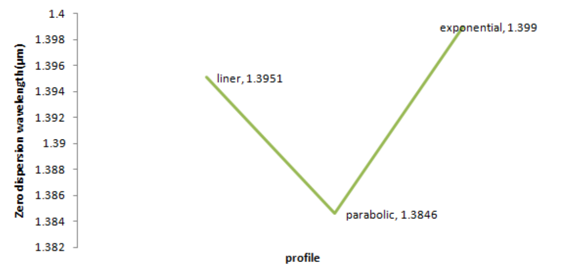

Figure 20. Zero dispersion wavelength

Three types of profile were taken which are linear, parabolic and exponential. On this section only the performance characterization curve would be shown. Among the three profiles zero dispersion wavelength is lowest in parabolic profile highest in exponential profile. So for better design of single mode graded index fiber parabolic profile is most suitable.

Cutoff wavelength at LP 11 is calculated and expressed as a graph below.

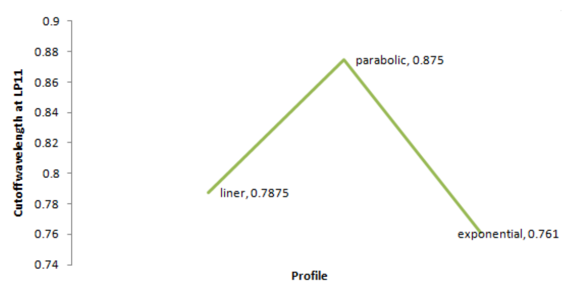

Figure 21. Cutoff wavelength at LP 11

Cutoff wavelength is higher in parabolic profile but lower in exponential. The values of the cutoff wavelength are less than 1 and apparently less than the values of single mode step index fiber.

Effective mode field diameter is analyzed at 1.31 µm and 1.55 µm. The values are shown in form of columns for suitable measurement.

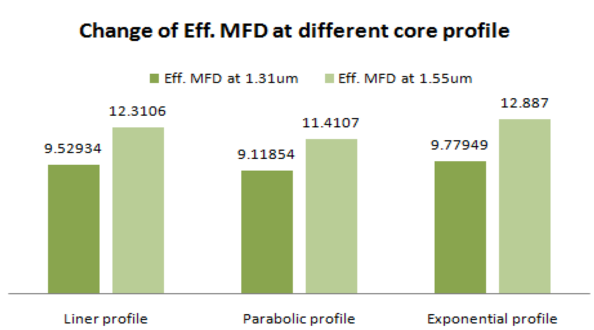

Figure 22. Effective mode field diameter.

Eff. MFD of parabolic profile is lower than two other profiles. In case of exponential profile the effective MFD is slightly higher than linear profile.MFD of this design is greater than the MFD of single mode step index fiber. It is because for the grading of core. As the values are more or less equal so in considering Eff. MFD it is not a must to select a specific fiber profile. The designer can select any of these three profile which suits better optimization to carry out his specific requirement.

Estimation of splice loss at 1.31 µm and 1.55 µm is graphically represented in the following figure-

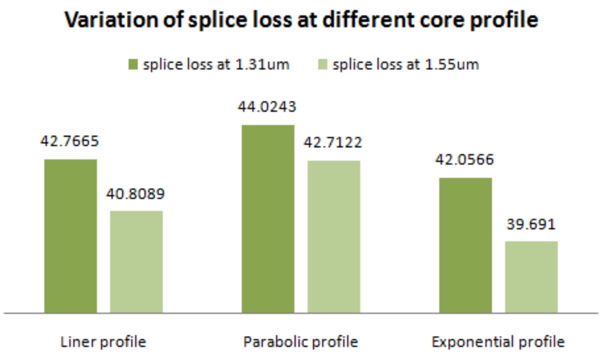

Figure 23. Splice loss

Splice loss is greater in parabolic profile but lower in exponential profile. Hence parabolic profile is suitable considering other technological parameters. So the slight increase in splice loss will not be a designers concern.

V. DISCUSSION

The parabolic profile results in continual refocusing of the rays in the core, and minimizes modal dispersion. In figure 9, parabolic profile is designed. And with the same time linear profile is also designed figure 11. By observing confinement characteristics of figure 10 and 12 we found parabolic profile is more suitable.

In multimode grading scheme dispersion characteristics enhanced the output. According to the figure 15 when 14 modes are selected we saw from mode 5 to 7 we have positive dispersion. So this area should be avoided while designing. When 20 modes are selected (figure16) dispersion align with the negative side more.

For bending loss characteristic we observed the output for different profile and different mode numbers selected, we found a large number of dispersion (figure 17) from mode 6 to 9 where bending loss increases linearly and after mode 9 it decreases sharply until mode 10 is reached. The bending loss characteristic curve is changed in figure 18 undesirably from 15 to 20 modes. (Here 20 modes were selected). So for better design this range of mode should be avoided.

VI. CONCLUSION

For single mode, the core and cladding diameter remain the same in designing that kind of fiber which is mentioned earlier. Among the several profiles the various parameters- zero dispersion wavelength, splice loss, bending loss, material loss and confinement characteristics meet the optimum standard if parabolic profile is selected. So for better design and implementation of single mode graded index fiber parabolic profile is most appropriate.

It is mentionable that not only in single mode but also in multimode fiber using parabolic profile is advantageous. In trial design for analysis we selected 15 modes but mode 5→7 meets high dispersion, mode 6→10 gives high bending loss. Selecting core diameter as 100µm and cladding diameter As 120 µm gives better performance.

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