Simulation of Few Mode Fiber Modes

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***Abstract*— This research explores the characteristics of modes in optical fibers at a wavelength of 633 nm. It examines how multiple modes can be utilized to transmit data simultaneously on the same wavelength through an optical fiber. This capability is dependent on the power content carried by each mode during the launching process. We have conducted both simulation and experimental analysis. Experimental results agree very well with the simulated findings.**

***Keywords*— few modes, LP modes.**

I. Introduction

A step index fiber (SIF) consists of a central glass core having refractive index n_1 surrounded by a cladding layer of slightly lower refractive index n_2. In a single-mode fiber (SMF), only one mode can propagate, a multimode fiber, allows many modes to propagate and few mode fibers support more than one mode [1]. In this study, we employed a 1550 nm fiber that functions as a few-mode fiber at a wavelength of 633 nm. A He-Ne laser was utilized as the source of 633 nm light. To analyze the power content of the supported LP modes, we used commercial software, determining which modes can serve as carriers. By different launching angles and positional combinations of the laser light at the fiber launching end we checked which combination is working well to launch more power into a particular mode so that can be used as carrier for user data. The same carrier modes we have generated very well experimentally in our lab as shown in table II also.

II. Mathematical forumlation

Numerical aperture (NA) is defined as:

$$\mathrm{NA}=\sqrt{n_1^2-n_2^2}$$

The normalized frequency V governs the number of modes(M) as well as their propagation constants. There could be just one mode if V<2.4048, though. Conversely, if V exceeds 2.4048, then more than one mode exists. It is defined as:

$$V = k_0 a NA$$

where $k_0 = \frac{2\pi}{\lambda_0}$, λ_0 *is the wavelength of li*ght and a is the core radius.

The effective refractive index (n_{eff}) is related to the propagation constant β as:

$$n_{eff} = \frac{\beta}{k_0}$$

The effective area of the fundamental mode is [2]:

$$A_{eff} = \pi\omega_0^2$$

where ω_0 is the spot size of the fundamental mode and is given by,

$$\frac{\omega_0}{a} \approx 0.65 + 1.619V^{-3/2} + 2.819V^{-6}$$

The percentage power of the fundamental mode is given by,

$$\text{P in core} = [1 - \exp(-\frac{2a^2}{\omega_0^2})] \times 100\%$$

The mode cut of wavelength is defined as [3]

$$\lambda_{co} = \frac{2\pi}{V_{co}} aNA$$

where V_{co} is the cut-off frequency of the linearly polarized ($LP_{l,m}$) mode below which It can not exist as shown in below where l=0,1,2… and m=1,2,3… [1]

The fractional modal power in the core is given by [3]:

$$P_{core} = \text{const.}\int_0^a \int_0^{2\pi} |\psi|^2 \text{ r dr d}\phi$$
$$= \frac{2C}{J_l^2(U)} \int_0^a J_l^2(\frac{Ur}{a}) \text{ r dr} \int_0^{2\pi} cos^2 \, l\phi \, d\phi$$

$$P_{core} = C \frac{\pi a^2}{U^2} \frac{2}{J_l^2(U)} \int_0^U J_l^2(x) \text{ x dx}$$
$$= C \pi a^2 [1 - \frac{J_{l-1}(U) J_{l+1}(U)}{J_l^2(U)}]$$

Percentage modal power in the core is given by:

$$\%P_{core} = C \pi a^2 [1 - \frac{J_{l-1}(U) J_{l+1}(U)}{J_l^2(U)}] \times 100\% \qquad (1)$$

where x=Ur/a
and 'C' is a constant (its use has been made of standard integrals associated with Bessel functions), 'a' is the fiber core radius, 'l' is the azimuthal index, 'Ψ' is the complete transverse field, and λ_0 is the wavelength.

$$U = a(k_0^2 n_1^2 - \beta^2)^{1/2}$$

III. Results and discussion

In this work, a commercial software we have used. Inputs in this calculator are: core radius = 5 μm, n_1 = 1.445, n_2 = 1.44 and λ_0= 633 nm. Waist radius of 5 μm and launching position at fiber end and angle orientation as show in the table I below.

TABLE I.

Cases	Launching position (μm)	Angular orientation	Modes	Power carried by modes
Case 1	x=0, y=0, z=0	x=0° y=0°	$LP_{0,1}$	91.96%

Case 2	x= 0.3 y=0.5 z= 2.5	x=3.5° y= 3.9°	$LP_{0,2}$	13.82%
Case 3	x= 2.6 y= 5.1 z=1	x=0.5° y=1.9°	$LP_{0,3}$	11.67%

In case 1(Fig.1), at a launching position of x=0, y=0, z=0 with an angular orientation of x=0° and y=0°, the $LP_{0,1}$ mode displayed the maximum power content, representing 91.96% of the total launched power, which was 94.80% under these conditions. In case 2(Fig.2), at launching position of x=0.3, y=0.5, z=2.5 with an angular orientation of x=3.5° and y=3.9°, the $LP_{0,2}$ mode exhibited the maximum power. It is carrying 13.82% of the total launched power, which was 48.30% under this condition and in case 3(Fig.3), at a launching position of x=2.6 y=5.1, z=1 with an angular orientation of x=0.5° and y=1.9°, the $LP_{0,3}$ mode had the highest power content, comprising 11.67% of the total launched power, which was 35.90% in this scenario. Total launched power is calculated using (1). Case 1 and case 2 simulation results have also been verified very well by experiment show in table II that is showing composition of dominant modes respectively in first and second row in respective cases.

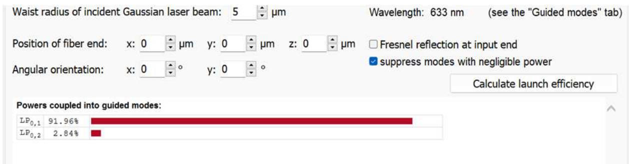


Fig. 1. Case1

Fig. 2. Case2

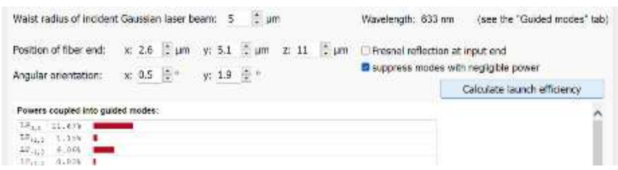
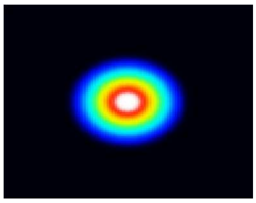
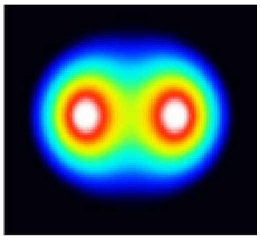
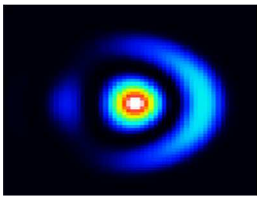
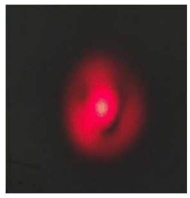


Fig 3. Case3

IV. Conclusion

Depending on the launching conditions different modes could be excited. The results in table I indicate that data can be simultaneously transmitted by different users using the $LP_{0,1}$, $LP_{0,2}$, and $LP_{0,3}$ modes as carriers at the same wavelength of 633nm. Since $LP_{0,1}$ is carrying most of the power (91.96%) among 94.80% total launched power, $LP_{0,2}$ is carrying most of the power (13.82%) among total launched 48.30% and $LP_{0,3}$ mode is also carrying 11.67 % out of total launched power of 48.30% under their respective launching conditions. These excited modes can be effectively used as carriers for efficient and effective communications. The following experimental study emphasizes the power dependence on the angle of launching or incidence. Such modes we have also generated experimentally using He-Ne laser and 1550 single mode fiber that works as Few mode/Multi mode fiber for 633 nm wavelength. mode fiber for 633 nm wavelength.

TABLE II. Modes Simulated and Experimented

Modes	Modes by Simulation 	Modes by Experiment
$LP_{0,1}$		
$LP_{0,1}$ and $LP_{1,1}$		
$LP_{0,2}$ and $LP_{1,1}$		

V. References

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