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# Wavelength and beam launching effects on silica optical fiber in local area networks

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ABSTRACT

In this paper, we report the modal dispersion of silica graded-index optical fibers as a function of the input mode parameters and lunching conditions in local area network (LAN) context. In that, we examine the mode-depending parameters, namely, modal delay, modal attenuation and mode-coupling effects as a function of wavelength. We show that the number of excited mode groups depends strongly on the spot beam radius when the fiber is excited with an axial Gaussian beam where we find an optimal axial diameter exciting only two mode groups. We present a comparison of the number of excited mode groups, the optimal spot radius beam, the signal penalty and the 3-dB baseband bandwidth enhancement for the optimal axial launching compared with full mode excitation, offset launching and mode-field matched axial launching.


## 1. Introduction

Nowadays the growing demand for high data rate applications via internet requires a reliable transmission media such as optical fibers. Compared with wireless/wired communications, optical fiber communications is known to offer high transmission capacity with low attenuation. There are two different families of optical fibers used in optical communication systems, namely, single mode fibers (SMFs) and multimode fibers (MMFs). The single mode fibers have a small core diameter between 8 and 10 µm where they operate in the lowest-loss windows at 850 nm, 1300 nm and 1550 nm. Compared with MMFs, SMFs offer less model dispersion, however it suffers from chromatic effects [1]. Therefore SMFs are likely used for long distance as in transatlantic connections. There are two different types of MMFs, namely; step-index and graded-index MMFs. With the larger core size, and hence their lower cost, MMFs are deployed as the backbone in various transmission systems such as local area networks (LANs), storage area networks (SANs) and wireless local area networks (WLANs) [2].

There are two standards of MMF, namely 50/125 µm and 62.5/125 µm diameters. In this work, we have focused our study on graded-index 50/125 µm silica optical MMFs used in optical networks (e.g., Ethernet, fiber channel, and fiber distributed data interface (FDDI), asynchronous transfer mode (ATM)). In MMFs, there are several modes that propagate along the fiber length, and this leads to modal dispersion, a phenomenon which depends on factors such as material dispersion, the launching conditions and mode-depending characteristics. In our study, we classify mode-depending effects as a function of modal delay, modal attenuation and mode-coupling. Modal attenuation is caused by internal MMF effects; whereas mode-coupling is produced from internal and external factors. In the literature, two principal techniques are used for exciting modes in MMFs, namely axial launching and offset launching. In order to enhance the 3-dB MMF bandwidth and to decrease signal penalty caused by modal dispersion, in this work the axial launching technique is used with an optimal spot radius beam.

The modal transfer function of MMF is obtained by numerically solving the power flow equation in the frequency domain. In that, we approximate the calculation with the adaptive Simpson quadrature method [3,4]. Also we show that modal transfer function can be written with the modal power distribution as a function of a normalized mode number, wavelength, fiber transmission length and baseband angular frequency.

The paper is organized as follows. In Section 2, we present the modal dispersion model based on the power flow equation resolution, where we discuss different parameters as a function of wavelength windows. In Section 3, we examine the launching condition of optical fibers with an axial Gaussian beam where a good agreement between the number of excited mode groups and the input spot radius is presented. Finally, in Section 4, we present simulation results of the modal transfer function of MMFs taking into account modal dispersion and optimal launching conditions.

## 2. Dispersion model

Dispersion is generally classified as intermodal, chromatic and polarization mode dispersion (PMD). Given the long propagation

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distance in access networks, G652 monomode fiber optics are commonly deployed to reduce the effects of intermodal dispersion. The PMD is caused by asymmetries and stress distribution on the fiber core, which lead to birefringence. Therefore this type of dispersion only appears in long-haul communication systems. Nonlinear effects in optical fibers can also cause negative effects on the system performance, but mainly for long-distance communications. Such nonlinearities are dependent on the signal intensity, which are not significant at low power. The stimulated Brillouin scattering (SBS) is also an important nonlinear limiting factor in transmitting high power signals at long distance such as WDM [5] and OCDMA systems [6]. The SBS effect depends on several parameters including the fiber type, the core diameter and the linewidth of laser output spectrum. Chromatic dispersion is one of the most important modal properties of fibers where it is the main contributor to optical pulse broadening. This type of dispersion is mainly due to the combined effects of material and waveguide dispersion.

### 2.1. VCSEL parameters

The proposed system model is composed of three elements; optical transceiver, optical channel and optical receiver. There are two types of surface emitting device such as vertical cavity surface emitting lasers (VCSELs) used in 10 Gigabit Ethernet (10 GbE) MMF system [7] and the light emitting diode (LED). The VCSELs is the best choice in LAN context for their low cost and simple alignment into multimode fiber [8].

The spatial characteristics of the VCSEL output can be estimated by fitting the guided light into a Gaussian beam and then by calculating the near-field pattern. In practical systems, a lens can be placed after the laser facet to focus the diverging Gaussian beam emitted by the laser which can then be matched to the fiber mode [9].

We will consider the laser spectrum to have a Gaussian distribution of the form [3]:

$$P(\lambda,\lambda_0) = \frac{1}{\sigma_\lambda\sqrt{2\pi}}\exp\left[-(\lambda-\lambda_0)^2/2\sigma_\lambda^2\right] \quad (1)$$

The rms spectral linewidth, considering the approach of [10], is defined by:

$$\sigma_\lambda \geq \frac{\lambda^2}{\pi a N_1(\lambda)}\left[\frac{\alpha\Delta(\lambda)}{\alpha+2}\right]^{1/2}\left(\frac{m}{M(\lambda)}\right)^{\frac{\alpha-2}{\alpha+2}} \quad (2)$$

where $N_1(\lambda)$ is the material group index defined by $N_1(\lambda) = n_1(\lambda)-\lambda n_1'(\lambda)$ in which the prime means derivative with respect to wavelength, and $m$ is the principal mode number explored in the next section.

### 2.2. MMF parameters

In this study we consider a graded-index optical fiber, shown in Fig. 1, characterised by $\alpha$-class refractive-index profile which can be expressed as:

$$n(r,\lambda) = \left\{\begin{array}{ll} n_1(\lambda)\left[1-2\Delta(\lambda)\left(\frac{r}{a}\right)^\alpha\right]^{1/2} & 0\leq r\leq a \\ n_1(\lambda)[1-2\Delta(\lambda)]^{1/2} & r\geq a \end{array}\right\} \quad (3)$$

where $r$ is an offset distance from the core centre, $\lambda$ is the wavelength emitted by the laser, $\alpha$ is the index exponent, $n_1(\lambda)$ is the core peak index, $\Delta(\lambda)$ is the refractive-index contrast and $a$ is the core radius of the fiber. The refractive index of silica fiber is described with Sellmeier equation as [10]:

$$n_1^2(\lambda) = \left[1 + \frac{A_0\lambda^2}{(\lambda^2-\lambda^2 0)} + \frac{A_1\lambda^2}{(\lambda^2-\lambda^2 1)} + \frac{A_2\lambda^2}{(\lambda^2-\lambda^2 2)}\right] \quad (4)$$

where $A_0$, $A_1$, $A_2$, $\lambda_0$, $\lambda_1$ and $\lambda_2$ are defined as Sellmeier coefficients.

It is already known that MMF supports a finite number of optical modes which can be analysed by solving the Maxwell's equations. In this case, guided optical modes can be grouped into families of modes with propagation properties described by the same propagation constant. In a MMF, the total number of mode groups that can be guided is given by [3]:

$$M(\lambda) = 2\pi a\frac{n_1(\lambda)}{\lambda}\left[\frac{\alpha\Delta(\lambda)}{\alpha+2}\right]^{1/2} \quad (5)$$

Given the transfer functions of the chromatic dispersion, $H_{\mathrm{chromatic}}(\lambda,z,\omega)$, and the modal dispersion, $H_{\mathrm{modal}}(\lambda,z,\omega)$, the transfer function of the MMF can be modelled by [4]:

$$H_{\mathrm{MMF}}(\lambda,z,\omega) = H_{\mathrm{chromatic}}(\lambda,z,w)H_{\mathrm{modal}}(\lambda,z,\omega) \quad (6)$$

where $z$ is the fiber transmission length, and $\omega$ represents the baseband angular frequency. In our work, we focus only on modal dispersion with the modal transfer function of the MMF is represented by [3]:

$$H_{\mathrm{modal}}(\lambda,z,\omega) = \int_{x_0}^{1} 2x\Re(x,\lambda,z,\omega)dx \quad (7)$$

where $\Re(x,\lambda,z,\omega)$ is the modal power distribution, and $x$ is the normalized mode group number, defined as $x = \frac{m}{M(\lambda)}$ with $m$ being the principal mode number. Note that the mode number $m$ is a

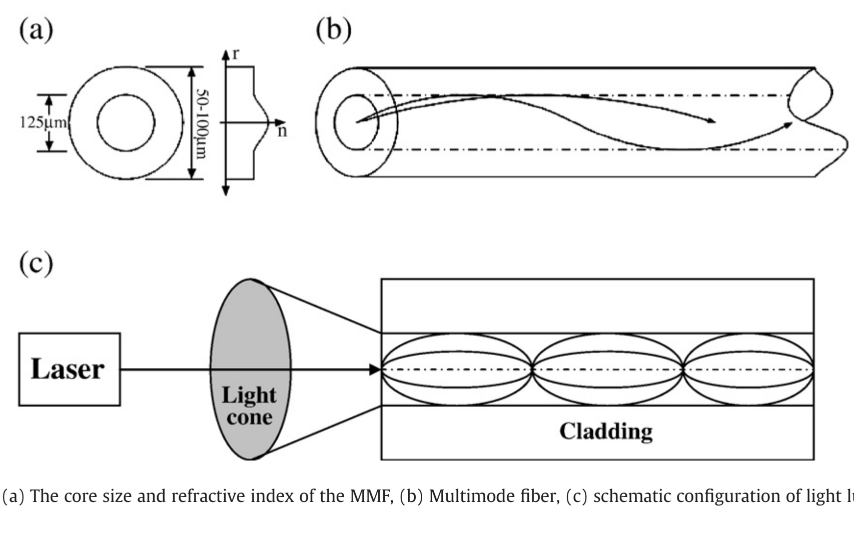


**Fig. 1.** (a) The core size and refractive index of the MMF, (b) Multimode fiber, (c) schematic configuration of light lunching.