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# Studying the effect of changing Input conditions on MMF using MGDM technique

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**ABSTRACT**

The mode group diversity multiplexing (MGDM) multicast technology uses optical multiple input and output (O-MIMO) technology to provide greater capacity and the ability to transmit information over multi-mode fiber (MMF). The MGDM system has a benefit in terms of capacity expansion, which led to interest in its use in most optical communications. The MGDM exploits the optical fiber bandwidth by inserting spatial light detection, which increases the capacity of the MMF. This research aims to study the optical systems used for the MGDM technology, and to identify the methods of their analysis and design of O-MIMO systems to increase the amplitude of this signal. The conditions of light entry into the optical fiber such as typical spot size, radial displacements, angle, wavelength, and radius of the detectors sections are improved. Numerical MATLAB simulation is used to improve the amplitude of graded index multimode fiber (GI-MMF) and compared to the existing aggregation systems. Moreover, this method was simulated to improve the input and detection conditions to increase the O-MIMO capacity using the MGDM technique. Finally, the capacity of the MGDM system was studied and compared with different channels, and it is noticed that the capacity of the system increases with increasing the number of channels.



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## 1. INTRODUCTION

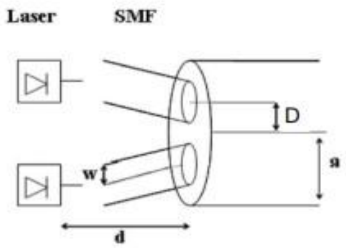
In modern local area network (LAN), the graded index multimode fiber (GI-MMF), is one of the basic types of optical fibers used for communication systems [1]–[3]. Due to its very large bandwidth, it is the primary transmission medium that provides broadband services using aggregation techniques. Among these technologies, the mode group diversity multiplexing (MGDM) represents a method for integrating various services across the multi-mode fiber (MMF), by inducing different sets of modes, which can be used as independent and parallel communication channels [4]–[7]. Wireless multi-input multi-output (MIMO) systems became that the transmitter diversity and receiver diversity widely used to counter multipath fading [8], [9]. It is possible to reduce the probability of error and ensure a reliable connection. By sending signals from several antennas or receiving signals with multiple antennas simultaneously [10], [11]. For a spatial multiplex system, the channel state information represents the information about the current value of the matrix, which is a mathematical value that expresses the channel signal, and then this information is used by predicting the effect of the channel [12].

Increasing the bandwidth as well as improving the signal quality is one of the most important problems facing the MMF optical fiber. There are several techniques which have been studied and applied in the MMF optical fiber bandwidth optimization. The first technique is applied to increase the channel capacity such as optical code division multiple access (OCDMA) and optical time division multiplexing (OTDM) techniques as in [13]. It has been illustrated hybrid optical systems of OCDMA and OTDM to get an increasing in the number of simultaneous users. It is shown that it can get wide-band facility by using different channels of the OTDM system. The second one, which is used the orthogonal frequency division multiplexing (OFDM), MIMO, and radio over-fiber (ROF) as reported in [14]. This work focused on improving the signal transmitted quality using three above technologies. It was obtained higher bandwidth in high speed railway HSR communications as well as improving the signal transmitted quality. In the last method, it is used MGDM technique as studied in [15]. This work is found the transmission capacity by using 2x2 MGDM technique through changing the injection parameters in the MMF optical fiber and using MIMO systems.

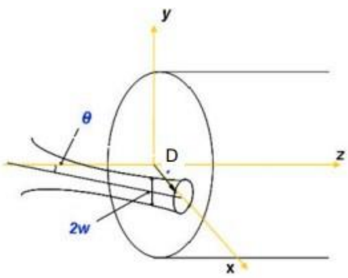
The aim of this work is to use 2×2, 3×3, and 4×4 MGDM technology and MIMO systems in MMF optical fiber, which was developed in the field of wireless communications by Chain and is known as basic local alignment search tool (BLAST). By adjusting the injection coefficients and changing the optical fiber length, to increase the transmitter channel capacity. It is obtained by increasing the channel capacity as increasing the number of channels. This work is organized as follows: section two is related to theory of the proposed method. The simulation results are discussed in section three. Finally, the conclusions are presented in section four.

## 2. THE PROPOSED METHOD

The MGDM aggregation channel is suitable for the wireless transmission channel named (BLAST). Optical data is sent for each user or service using a single-mode fiber of less than or equal to (1 m) in length, which determines the typical spot size (w) used on the input of the MMF fiber shown in (Figures 1(a) and 1(b)) [16], [17]. The arrival of the single-mode fiber with the MMF fiber on the transmitter side is using a light-coupler fiber (fiber connecter) [18], [19]. The receiver works through a lens which placed on the output of the fiber to receive the near right on an integrated optoelectronic circuit consisting of light detectors and amplifiers. There are several possible techniques to implement the transmitter and receiver in the MGDM system.




(a)




(b)

Figure 1. Determines the typical spot size (w) (a) the transmitter structure on the transmitter face of the optical fiber for SMF and (b) induction engineering of the MMF fiber through a diving field

The channel capacity for the matrix H is given in this expression [20]:

$$C = B.log2(\det [I_{NR} + \frac{\rho.s}{M} HH^{*}]) \quad (1)$$

Where B is bandwidth of the fiber; $I_{NR}$ is identity matrix NXN; $\frac{\rho.s}{N_T}$ is signal to noise ratio SNR, M is number of the mode in the MMF; $HH^{*}$ is the conjugate transport.

$$I\ (S, L)=f(E, S) \quad (2)$$

Where I is the electromagnetic field that is determined at a distance L in the MMF fiber with Cartesian coordinates. The mathematical model for amount propagation in a multimode fiber uses the Helmholtz equation:

$$\nabla_t^2 \Psi_{\mu,v} + K_0^2 n^2 \Psi_{\mu,v} = \beta_{\mu,v} \Psi_{\mu,v} \quad (3)$$

This equation describes the propagation of the electromagnetic field in Cartesian coordinates in a material described by the level of permeability μ and permittivity $\varepsilon$.

$$E_{(X,Y,Z)} = \sum a_{\mu,v}(z)\Psi_{\mu,v}(x,y)exp\left[-j(\beta_{\mu,v}(z)\right] \quad (4)$$

Where (μ,$v$) is the electromagnetic field mode; $a_{\mu,v}(z)$ is pattern amplitude; $\Psi_{\mu,v}(x,y)$ is the field of the propagation; $\beta_{\mu,v}$ is the propagation constant.

$$W_0 = \sqrt{\frac{2a}{K_0 n_0 \sqrt{2\Delta}}} \quad (5)$$

Where $W_0$ is the beam waist; W is the spot size; $a$ is the profile parameter that gives the profile properties of the refractive index of the fiber core, K0=$2\pi/\lambda$

$$\beta_{\mu,v} = \frac{\sqrt{K_0^2\beta_0^2 - 2(2\mu+2v+2)}}{\sqrt{W_0^2}} \quad (6)$$

Where: $v = 1,2,3, \ldots ..$

$$a_{\mu,v}(0) = \iint E_{in}(x,y)\Psi_{\mu,v}(x,y)u_z dxdy \quad (7)$$

Where $u_z$ is a ray in the direction of the z-axis for MMF.

$$a_{\mu,v}(z) = a_{\mu,v}(0)\exp\left(-\gamma_{\mu,v}(z)\right) \quad (8)$$

Where $\gamma_{\mu,v}$ is the damping coefficient,

$$m = \mu + v + 1 \quad (9)$$

This equation represents the set of modes with the same propagation constant.

$$P_m(O) = \sum_{\mu=0}^{m=1} \left|a_{\mu,m-\mu-1}\right|^2 = f(D, W, W_0, \theta \quad (10)$$

The induced patterns change according to the displacement D, measurement of spot size w, angle $\theta$, and fiber specifications MMF [21], [22]. The MGDM technology works on the use of N independent optical transmitters on one side of the transmitter and M receiver on the other end so that (M=N). The platform concept of the MGDM system that shown in Figure 2. In the input side of the MMF, the N lasers as the laser array shoot different signals to N different mode groups. On the receiving side, the M detectors detect the power mix of several mode groups [23], [24].

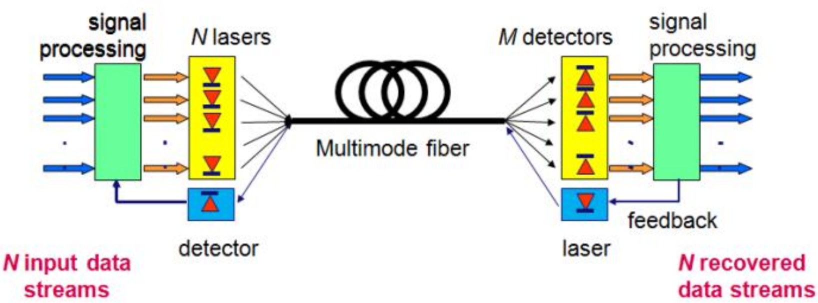



Figure 2. Photovoltaic system architecture using MGDM technology

If there are N inputs and M outputs, then the dimensional transport matrix (NXM) describes the propagation channel within the fiber [25]. The relationship between M is a received electrical signal (y). N is a transmitted electrical signal, Si, written in the form of a matrix [26], [27]:

$$Y = Hs + n \quad (11)$$

$$\begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_N \end{bmatrix} = \begin{bmatrix} H_{11} & H_{12} & \dots & H_{1N} \\ H_{21} & H_{22} & \dots & H_{2N} \\ \vdots & \vdots & \vdots & \vdots \\ H_{N1} & H_{N2} & \dots & H_{NN} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \\ \vdots \\ s_N \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_N \end{bmatrix} \quad (12)$$

Where Y is the received signal; s is the transmitted signal; n is the noise that added to the signal

$$H_{ij} = \frac{I_j(S_j,L)}{I_j(S,L)} \quad (13)$$

Where $I_j$ is the intensity of the luminous flux produced by the transmitter and is measured by the output of the fiber length L; Si is detector cross-sectional area measured at the fiber output; S is the total area of the fiber core.

## 3. RESULTS AND DISCUSSION

Figure 3 shows a simulation to find the value of the capacity versus the signal-to-noise ratio SNR and compare it for SISO and MGDM systems for a different number of channels. It is noticed that the capacitance increases significantly for a system MGDM (2X2), MGDM (3X3), MGDM (4X4) as compared with the system SISO. In the 3×3 MGDM system, three independent channels are transmitted in the GI-MMF (62.5/125) µm fiber by injecting light at three radiative displacements (F=0, 13, 26 µm), as shown in Figure 4, which shows that the higher the displacement. The light induction was of a high order, as it receives the light signals at the output of the fiber according to the radiative displacements within different regions. The near field model (NFP) is linked to the condition of selective induction at the input of the fiber. The NFP was detected. The output of the optical fiber with a length of L=75m was done by placing LEDs in front of each circular region or each sector related to the modular group induced on the fiber input according to a specific displacement.

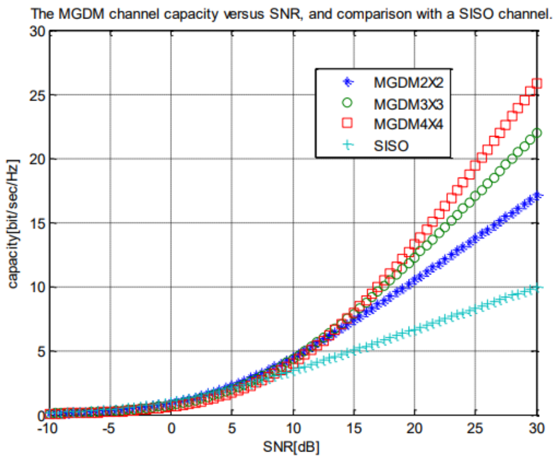



Figure 3. The relationship between the capacity with SNR for the MGDM & SISO channel

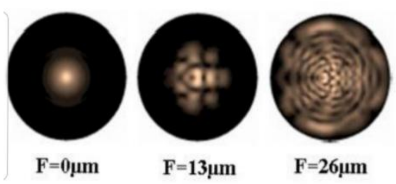



Figure 4. Near field diagram of a 75 m long MMF fiber on the output face of several radial displacements

Figure 5 shows the relationship between the power and number of the modes with several values of displacement D and spot size W. It is recorded the following points: i) When D=10 µm, a fiber (GI-MMF) (62.5/125) µm, wavelength=850 µm, core refractive index=1.5, L=100m, W=4 µm, 6 µm. Lower order patterns were induced at W=6 than at W=4, but with lower power amplitude, and ii) when D= 20 µm, a fiber (GI-MMF) (62.5/125) µm, wavelength=850 µm, core refractive index =1.5, L=100m, W=4 µm, 6 µm, 8 µm. In this case, high-order patterns are induced. It is noticed that decreasing in the ability of the induced patterns at a larger W=8 µm value. It can be seen that decreasing in the distributed modular power with an increasing in the radiated displacement D.

Figure 6 shows the comparison the power distribution of the patterns when taking the two highest values of spot size W=6 µm, 8 µm. This comparison reveals a clear decrease in the power of the patterns when the value of W increases to 8 µm. Figure 7 displays the power distribution of the induced patterns when working with optical windows is compared to 850 nm,1300 nm, and 1600 nm within a radial displacement of D=26 µm. It was found that the higher wavelength of 1600 nm contributed to the induction of lower-order modes with a higher typical power than the typical ability of the induced modes to work at other wavelengths. Changing the radial displacement to 13 µm elicits lower-order patterns and by comparing the typical power distribution for lengths (850, 1300, 1600) nm. It is found that increasing the wavelength induces lower-order patterns with higher modular power, as shown in Figure 8.

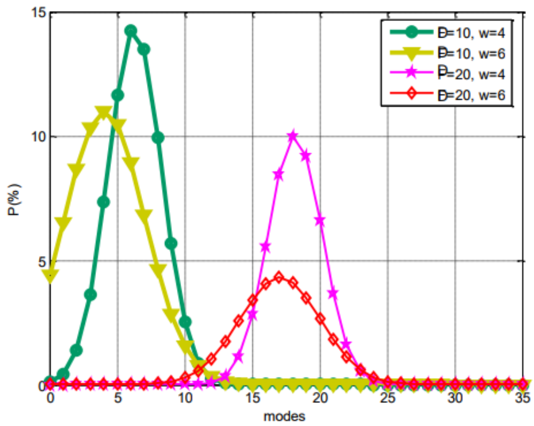



Figure 5. Relationship of optical power with modes at 850 µm wavelength and 100 m fiber length for different radial displacement D=(10,20) µm & W=(4,6) µm

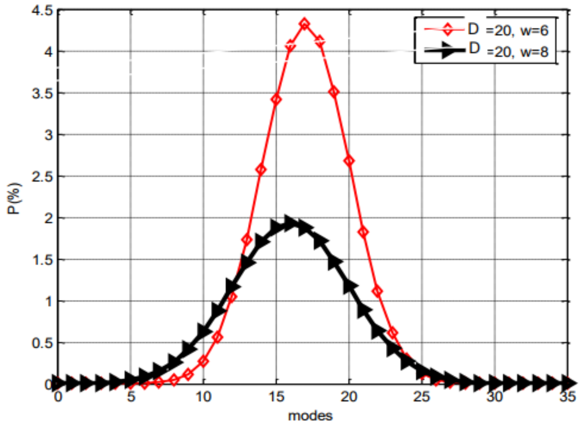



Figure 6. Relationship of optical power with modes at 850 µm wavelength and 100 m fiber length with radial displacement D=20 µm & W=(6,8) µm

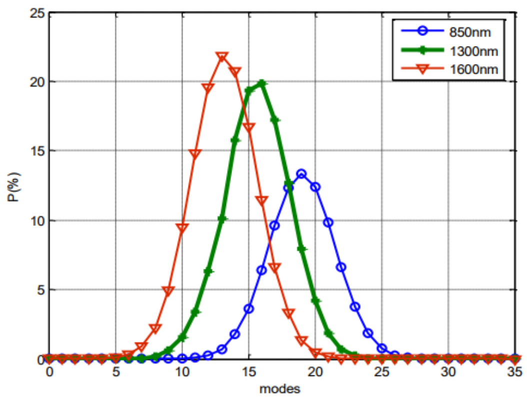



Figure 7. The effect of wavelengths on the distribution of optical power of induced patterns for D=26 µm

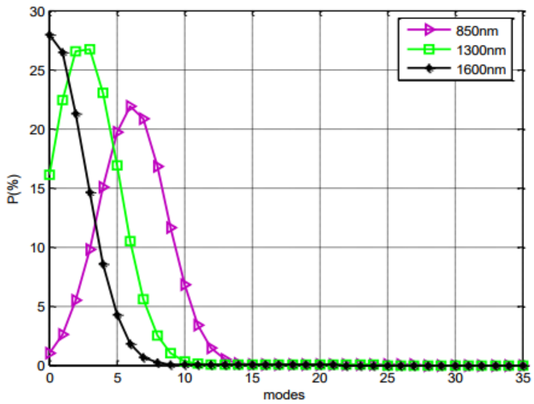



Figure 8. The effect of wavelengths on the distribution of optical power of induced patterns for D=13 µm

## 4. CONCLUSION

In this research, an analytical study and simulation of the MGDM assembly system were conducted, taking into account the different conditions of agitation and reception on the work of this system. It is used MATLAB program to obtain the best conditions for agitation. Low-order patterns are induced at low F radial displacements close to the fiber axis, and by increasing F displacement; high-order patterns are induced. Increasing the spot size w induces patterns of a lower order, but with less typical power than the distributed power of the patterns in the case of spot size of lower value. The capacity of the MGDM system was studied and compared with a different number of channels. Finally, it was noticed that the capacity of the system increases with the increasing in the number of channels.

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