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Design of Space Division Multiplexing with Six Polarized and Multiplexed Modes of PDM/DWDM System Using Multimode Splicer Enabling Gray mapping and MIMO Equilizer

Ibrahim Abdullah, Musaddak Maher

Department of electrical engineering, Engineering College, Babylon University
Hillah, Babylon, Iraq
www.theboss1@yahoo.com

Abstract

The paper demonstrates design framework for few-mode fiber based space division multiplexing (SDM) transmission system. In this paper six polarized and multiplexed modes used to obtain ultra-high data rate. Polarization dual multiplexing (PDM) and dense wavelength multiplexing (DWDM) techniques are also used in this system to increase total system data rate. Different DSP techniques like MIMO equalizer will be used to mitigate multi-mode fiber losses like chromatic dispersion CD, deferential group delay DGD, inter symbol interference ISI, and polarization mode dispersion. The proposed system is tested under different cases to obtain the required performance. Gray mapping enabled in this system to decrease BER values for different LP modes.

***Keywords**:* Few-mode fiber, SDM, CD, PDM, DWDM.

1. Introduction

With the noticed increase in Internet traffic, demand for much higher capacity will increase in optical communication networks to accommodate future high definition videos and new data communication services. The main goals in developing new wireless communication systems are increasing the transmission capacity and improving the spectrum efficiency [1]. Single-mode fiber (SMF) has been the best medium for high-capacity data transmission for over three decades. However, the exponential growth of internet traffic at about 2 dB per annum could exhaust the available capacity of SMF in the near future [2]. An important area of applications, driving the research that has led to many of the advances in photonics in the last thirty years is optical communications [2]. Space division multiplexing (SDM) in optical fiber link is expected to keep increasing the communication capacities besides the conventional multiplexing techniques [3]. The fiber-based space division multiplexing(SDM) techniques include mode-division multiplexing (MDM) using few-mode fibers (FMFs) [4], spatial multiplexing using multi-core fibers (MCFs) [5] or using helical excitation of different spatial angles [6], and orbital angular momentum (OAM) multiplexing using special ring fibers[7]. These new multiplexing techniques have also been introduced to free space optical communications. Today's SDM research is also occurring as coherent detection and digital compensation are capable of overcoming complex impairments (such as polarization mode dispersion (PMD) and are accepted as a standard part of high- performance systems. This is crucial: since SDM packs spatial channels tightly into each fibre, crosstalk

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between channels is an obvious potential disadvantage and needs to be addressed. The addition of significant crosstalk to a transmission line would have been particularly unattractive a few years ago, before coherent-detection systems offered hope of subtracting out crosstalk electronically at the receiver [8]. These enabling technologies have made SDM a viable strategy just as a severe need for innovation emerges [8]. Over the past forty years, a series of technological breakthroughs have allowed the capacity-per-fibre to increase around 10x every four years. Transmission technology has therefore thus far been able to keep up with the relentless, exponential growth of capacity demand. The cost of transmitting exponentially more data was also manageable, in large part because more data was transmitted over the same fibre by upgrading equipment at the fibre ends. But in the coming decade or so, an increasing number of fibres in real networks will reach their capacity limit [9].

2. System Description:

Single channel in high capacity SDM system with three spatial dimensions (fiber modes) is presented in this section as shown in figure (1). A Pseudo Random Binary Sequence (PRBS) generator contained in the Tx-mQAM PolMux module is desired to generate pseudo random binary sequences. PRBS produce 40 GB/s bit rate. By using polarization division multiplexing technique and three spatial modes for single channel, the total bit rate of system become (1Channel*3 modes*2 polarization states*40 GHz = 240 GHz). The demonstrated system tested under 16QAM modulation format. Linear losses like chromatic dispersion, PMD dispersion, DGD, deviation from ideal group delay, line width, and fading had been compensated using different techniques like FIR matched filter and DSP modules for CD compensating , and TDE MIMO techniques.

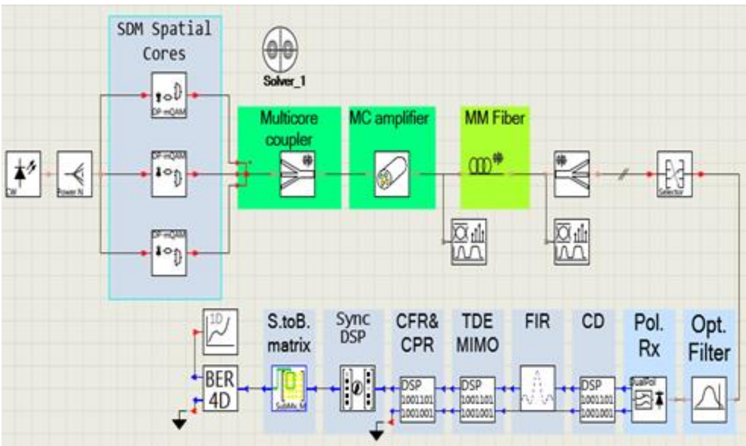

Figure (1): Single channel PDM-SDM System

1) Transmitter Section:

The simulated transmitter section of three cores SDM system is shown in figure (2).

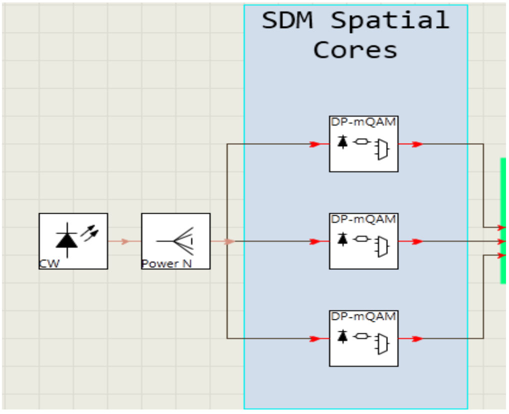

Figure (2): Transmitter section of 3-modes SDM System

The transmission structure of three modes SDM system consists of two parts, CW laser source and spatial fiber modes. The characterization of each part is shown below:

I. CW laser source:

The LaserCW module models a DFB laser producing continuous wave (CW) optical signal. The module produces a time dependent field E(t) describing the radiation of a CW laser with the specified power, frequency, linewidth, and polarization.

The produced single channel split into three spatial cores by power splitter module. This module acted as an optical power splitter so that the incoming signal is equally split on each output port.The simulated CW laser module parameters are shown in table (1).

Table (1) Parameters of the CW laser

Parameter	**Value**	**Units**
Emission frequency	193.1	THz
Power	-1,0,1	dBm
Line width	1e6	Hz
Output data type	Blocks	
Initial phase	0	degree

II. Spatial Dimensions (Fiber modes):

The output signals of power splitter distributed equally into the three spatial modes. We demonstrated a transmitter DP-mQAM module to be used for modulating and dual polarizing the incoming optical signals. This module modulated the incoming optical signals with 40 GHz bit rate with different modulation techniques. Polarization division multiplexing (PDM) also achieved by this module to increase the bit rate of system. The block diagram of DP-modulation transmitter is shown in figure (3).

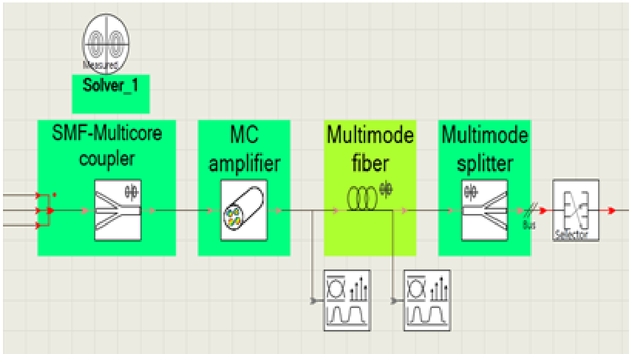

Figure (3): Block diagram of Tx-DP-modulation module

2) Multimode fiber channel section

The output spatial modes travel into few mode fiber (FMF) through a multicore ideal coupler. The supported modes are (LP01, LP11a, and LP11b). Mode solver parameters shown in table(4). The table of coupling matrix is shown in table (3). EDFA amplifier array model used to amplify the spatial modes. The EDFA acted as power control amplifier producing high output power with a gain of (15, 14.5, and 14.5) for (LP01, LP11a, and LP11b) modes respectively. The block diagram of EDFA array module is shown in figure (5).

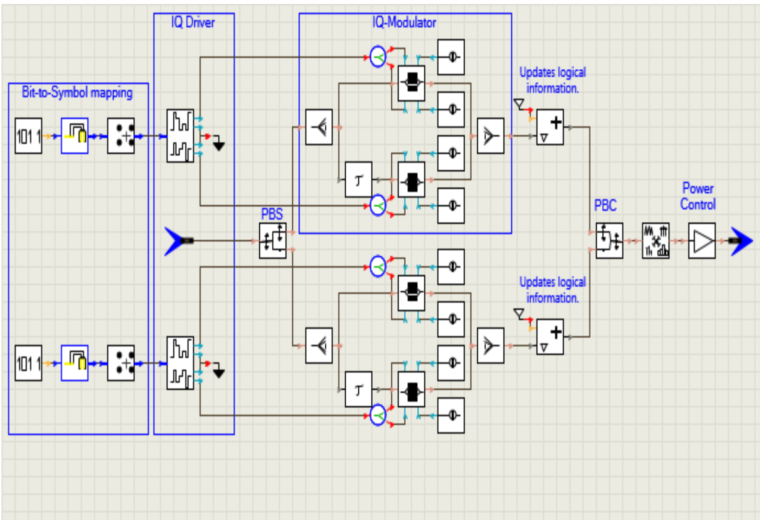

Figure (4): The block diagram of optical channel

Table (2): The parameter description of mode solver

Parameter	Value	Units
Refractive Index	1.4	
Supported modes	(0, 1) (1, 1) # LP01, LP11a,LP11b	
Attenuation	0.2e-3	dB/m
DGD	0,0.05e-12	
Intra mode GDD	5*10^-15	s/m
PMD	0.05e-12/31.62	s/m^2
Dispersion	20e-6	s/m^2
Dispersion slope	0.075e-12	s/m^3

Table (3): Parameters description of Multimode coupler

Coupling Matrix			
Port Number	**ModeID**	**Magnitude**	**Phase(deg)**
1	0	1	0
2	1	1	0
3	2	1	0

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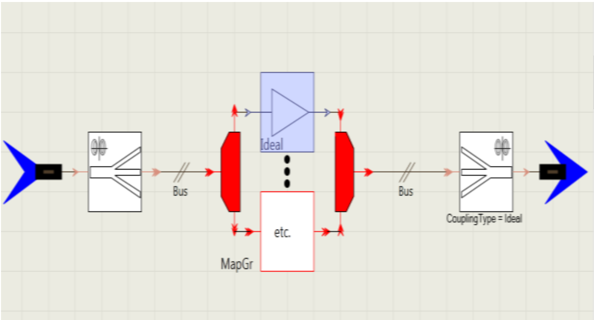

Figure(5): EDFA array block

3) Receiver Section

Now, the receiver section is presented. The block diagram for single channel receiver section is shown in figure (6). After bus selector using to choose cores to be decoded, an optical filter used to band pass the required channel to be processed in the selected core with Gaussian transfer function. Optical filter parameters description shown in table (6).

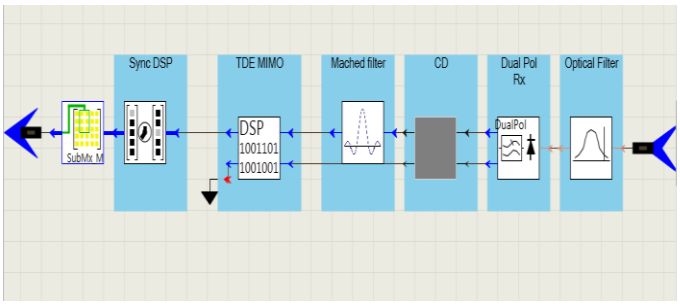

Figure (6): Block diagram of single channel receiver section

3. Results and Discussion:

I. Spectrum Result

Figure (4.1) shows the RF scope analyzer of single channel over 3modes SDM/PDM-16QAM signal before and after 1000 Km transmission distance using 40 Gb/s bit rate. Linear polarized modes and perfectly symmetric fiber assumed in our designed system. By using three modes and dual polarization state the total bit rate of our designed system become 240Gb/s.

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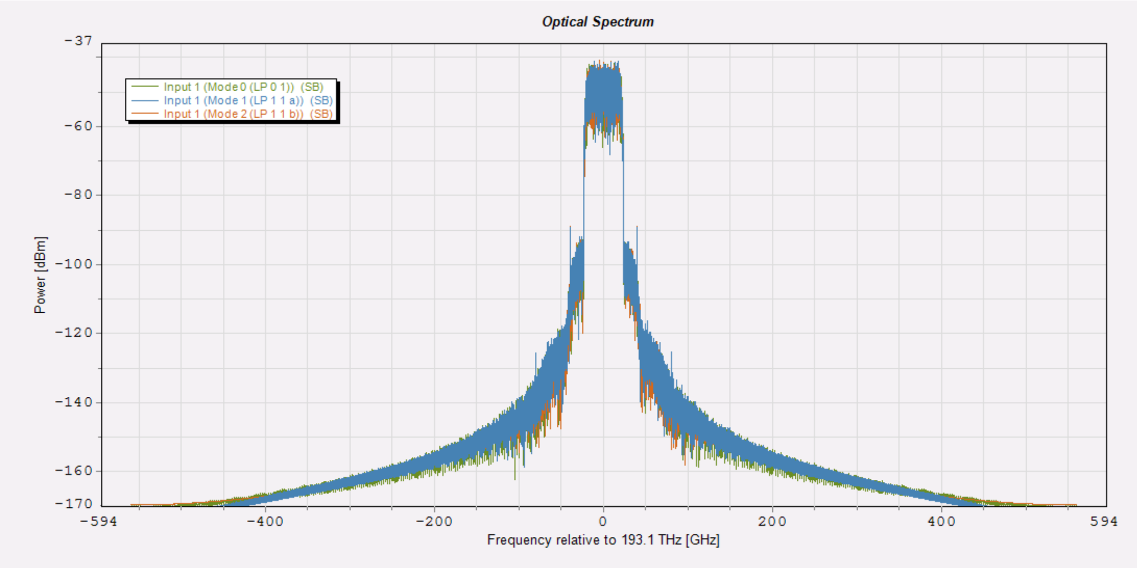
(a)



(b)

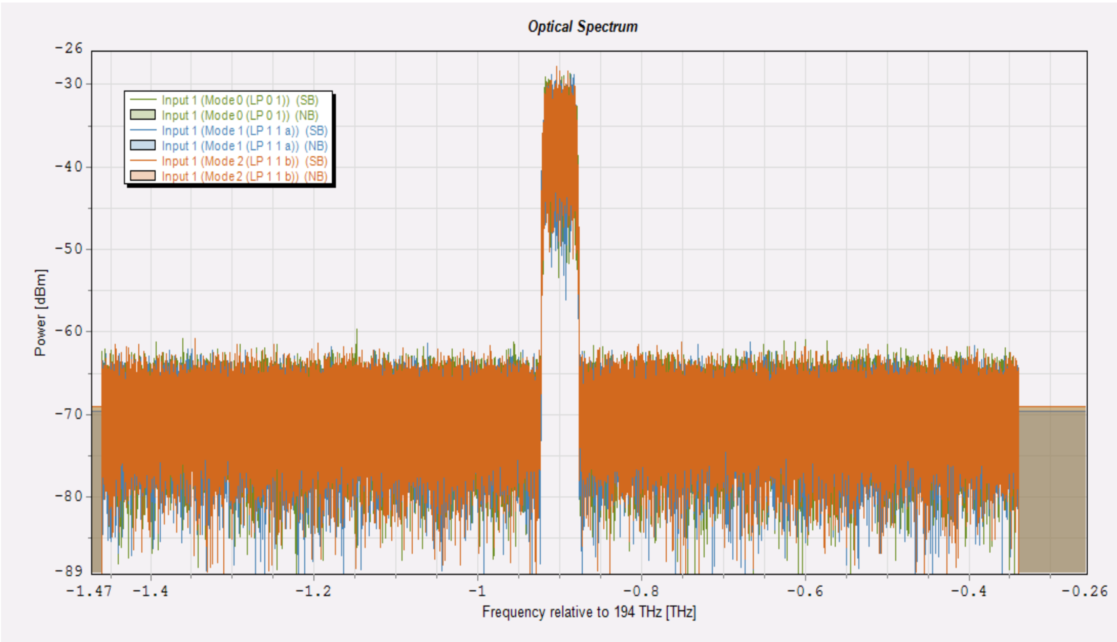


Figure (7): The spectrum of Optical OSA for single channel 3-modes SDM/PDM 16QAM system

(a)before and (b)after 1000 Km transmission reach.

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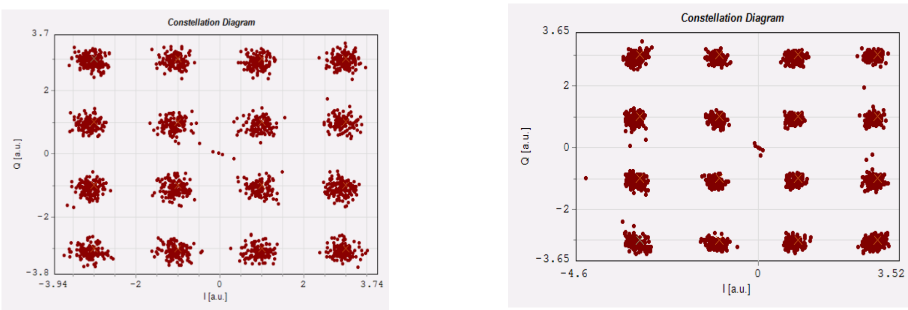
II. The Diagram of Received Electrical Constellation:

The diagram of received constellation for received single channel with 16QAM modulation format is presented in this section. The following cases of constellation results will be discussed to study the performance of system:

❖ **Gray mapping:**

Gray codes with two dimensions had been used in our designed system to mitigate the bit errors number in 16QAM format specified points in the constellation and as a result enhance the system performance . In gray coding the points of constellation in horizontal and vertical directions differ by one bit and two bits differs for diagonal points. The constellation diagrams using Gray code for channel 1X in LP01 mode are shown in figure (8).



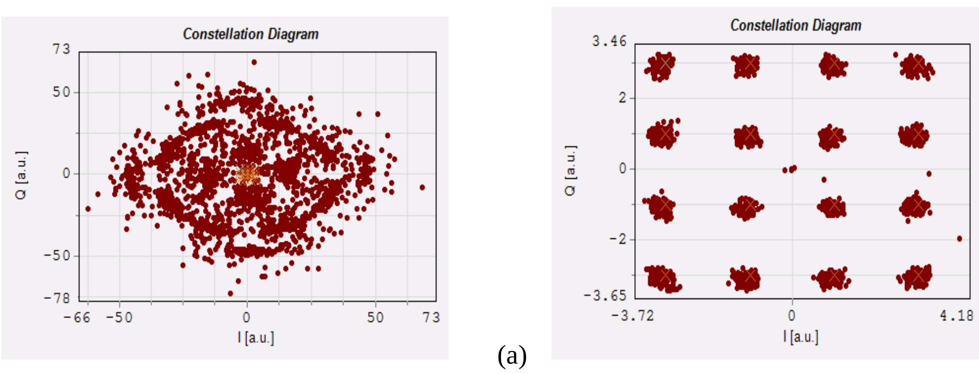
(a) (b)

Figure (8): Received constellation diagram of channel 1X in LP01 mode a. Without using gray mapping ,b. Using gray mapping

The system receiver capable of correcting any errors in transmission that cause deviate the constellation point into adjacent point area. This enhancement improved our system to be lower volatile to noise.

❖ **TDE MIMO adapter:**

Time domain equalization using multiple-input multiple-output (MIMO) technique had been used at the receiver of our proposed system to compensate large DMGD, intra-modal crosstalk that produced between LP01 and LP11 modes, and inter-modal crosstalk that produced between LP11a and LP11b modes. Decision-Directed (DD) LMS method or constant modulus algorithm (CMA) had been used as the best MIMO method. The number of filters taps used is (10) and the number of iterations is (15). By using this method, we achieved faster convergence and hence less symbols in the training sequence are needed with less hardware complexity and as a result best equalization performance. For example, the obtained result using TDE MIMO equalizer for LP01 mode is shown in figures below.



(a) (b)

Figure (9): Received constellation diagram of channel1X in LP01 mode (a) without using TDE MIMO equilizer, (b) using TDE MIMO

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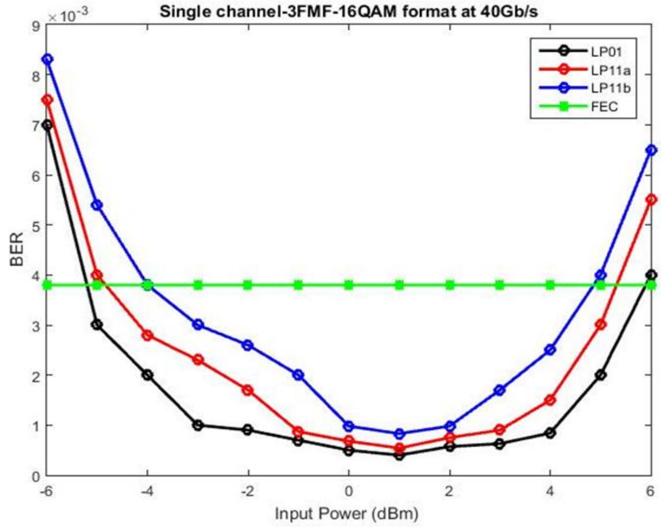
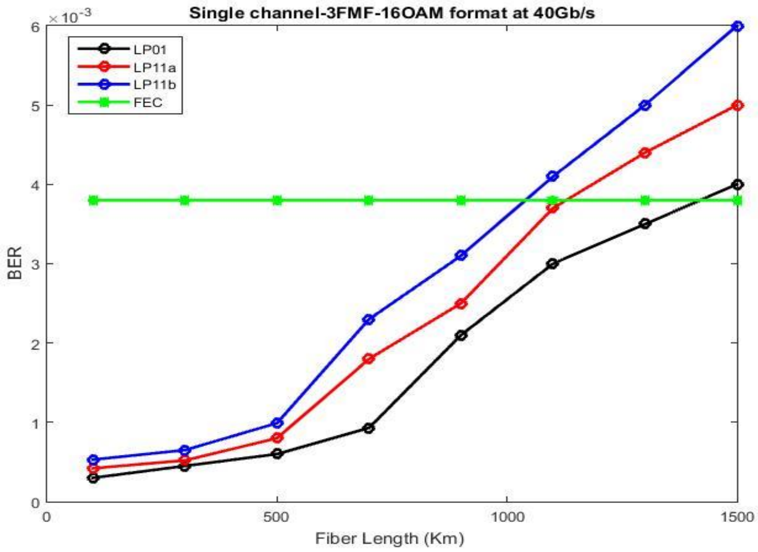
iii. Maximum Reach Measurements

To describe the transmission best performance of single channel 3 modes SDM/PDM-16QAM system, the most extreme achieve results were experimented as function of input power in the fiber and are appeared in figure (10). At 40Gbit/s Single channel 3 modes SDM/PDM-16QAM transmission the ideal input power was observed to be 1dBm, comparing to a greatest transmission length of 1020km.



Figure(10): Input power versus BER for single channel 3modes SDM/PDM-16QAM system

The diagram below shows the relationship between the few mode fiber length and bit error rate for the specified modes.



Figure(11): Diagram of LP modes specifying BER versus length for single channel 3-modes SDM/PDM-16QAM system.

4. Conclusion

In this paper, we designed simulation system for space division multiplexing combined with PDM/DWDM techniques. We achieved a long haul transmission using few mode fiber with a total bit rate of 240Gb/s. At 40Gbit/s single channel over 3 modes SDM/PDM-16QAM transmission system, the ideal input power was observed to be 1dBm, comparing to a greatest transmission length of 1020km. SDM transmission has shown its great potential to be a promising technology for the next generation optical network.

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A Brief Author Biography

Dr. Ibraheem Abdullah obtained his Ph.D. degree in electrical Engineering in 2005 and assistant professor degree in 2010. He is with the department of electrical engineering, university of Babylon, Hillah, Iraq. His interest in communication systems, digital signal processing, single mode optical fibers, and multi-mode fibers.

Eng. Musaddak Maher obtained his B.Sc. degree in electrical Engineering in 2010. He is currently a postgraduate master student in the department of electrical engineering, university of Babylon, Hillah, Iraq. His interest in optical fiber systems, space division multiplexing, and multi-mode fibers.

