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Design and Modeling of For Optical SDM Transmission Systems Enabling FMF with 14 Spatial and Polarized Modes

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ABSTRACT: *This paper explains simulation modeling and design for space division multiplexing (SDM) transmission system. For the ultra-high capacity need of SDM, we have proposed the few mode fiber (FMF) as SDM best technology for obtaining ultra-high bit rate systems with long haul transmission. Inter-core crosstalk that appears in higher-order- modes was the most problem to be resolved. We proposed 8-DWDM channels over 7 modes FMF system achieving a total bit rate of (2.4 THz) and the acceptable range of input power is from -1dBm to 2dBm. While the highest distance obtained is 760Km for 8-DWDM channels-7modes-SDM/PDM system.*

Keywords: *FMF, DWDM, QAM, PDM.*

I. INTRODUCTION

SDM has risen as a cutting edge innovation to manage the persistent movement development, to stay aware without bounds of Internet transfer speed necessity [1]. Among SDM advancements, SDM utilizing few-mode fiber (FMF) transmission has been widely investigated [2-3]. Since the routine multi-mode fiber (MMF) is not appropriate for long reach SDM transmission on account of its huge differential mode group delay (DMGD) and more than several spatial modes, the few-mode fiber is produced with just the backing of little number of spatial modes at moderately little DMGD [4].SDM had been presented as a great hopeful innovation to drastically enhance fiber limit [5].

The most important advances to build the speed of optical transmission framework are distinguished as follows:

1. Amplitude: First commercial optical transmission systems consisted in intensity modulation (on-off keying or OOK) of light along with direct detection at the receiver. Without any advanced processing at the receiver, the achieved bit rates that guaranteed an acceptable signal quality reached 10 Gigabits per second (Gb/s) over important distances. Increasing the bit rates to 40 and 100 Gb/s was not possible over the same distances because of higher optical signal to noise ratio (OSNR) requirements and a decreased robustness with respect to chromatic scattering and polarization mode scattering (6).

2. Time: Time domain division multiplexing (TDM) increases the transmission speed by time-multiplexing several lower bit-rate streams. Optical TDM multiplexes the signals optically. Therefore, the system electrical bandwidth requirement is relaxed and is related to the baud rate of each subcarrier. Because of the hardware constraint and the system stability, TDM is challenging to be used for the terabit per channel system design[7].

3. Polarization: Polarization is taking advantage of the vector nature of electromagnetic waves, especially in coherent detection, so we can transmit simultaneously on a set of two orthogonal polarizations by introducing correlations between the symbols of both polarizations, thus doubling the transmission capacity [8].

4. Wavelength: The impressive development of optical amplifiers enabled the transmission of independently modulated wavelengths over thousands of kilometers without opto-electrical regeneration, known as wavelength division multiplexing (WDM) illustrated in Fig. 1a. Modern WDM systems can transmit up to 80 channels in parallel over a 4 THz spectral window partitioned into 50 GHz slots. Each wavelength can be modulated at 10, 40 and currently 100 Gb/s yielding total capacities of more than 1 Terabit per second (Tb/s) over a single fiber [8].

Space is a degree of freedom which is not yet used in the fiber for multiplexing, and is being intensively investigated today for the next leap in capacity. Space division multiplexing (SDM) can be actualized with multi-mode fibers (MMFs) having a substantial center breadth allowing the propagation of more than one mode in contrast to the currently deployed single mode fibers (SMFs)[9]. SDM can also be realized through the use of multi-core fibers (MCFs) that have more than one core in the same cladding [10]. The available spatial modes or cores form an orthogonal set of channels over which independent data symbols can be multiplexed and transmitted. A WDM/SDM/PDM optical transmission system is strongly imposing itself as a future Peta bit achieving solution for short-reach, metropolitan, long-haul or any point-to-point ultra-high-capacity link as reported in [9-10]. Figure (1) indicates distinctive approaches to balance and multiplex channels to expand framework limit in optical transmission.

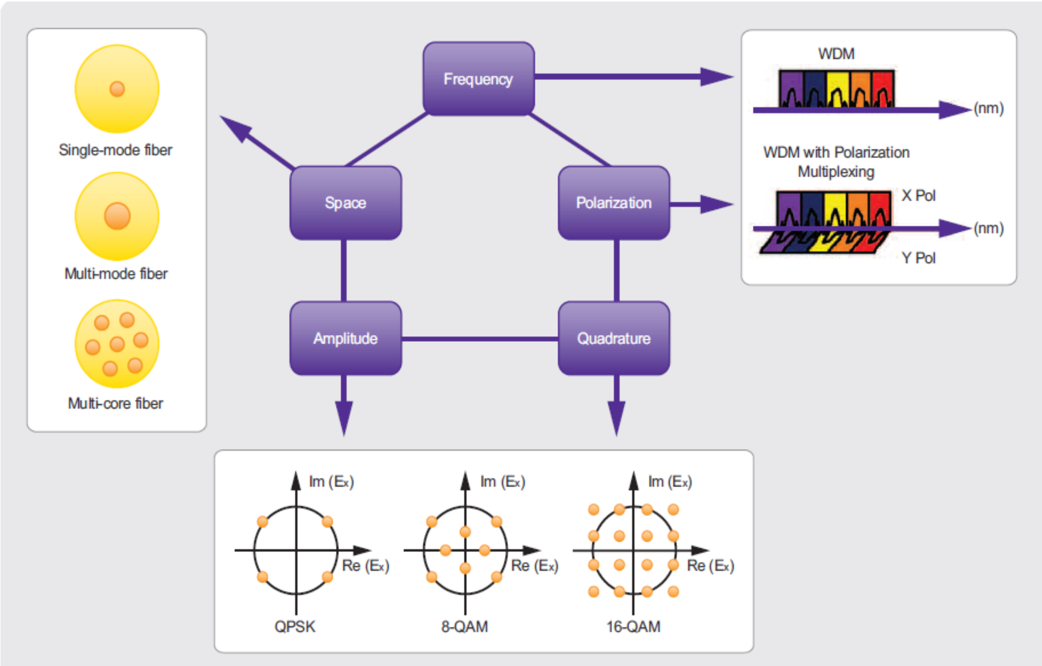


Fig.(1): Multiplex techniques of optical communication systems [6]

II. SYSTEM DISCRIPSION

To increase the transmission reach of the optical signal and enhance the system performance, the system must be designed properly by accurate selection of the various components in the system. In this paper, we proposed DWDM/PDM/SDM transmission system.

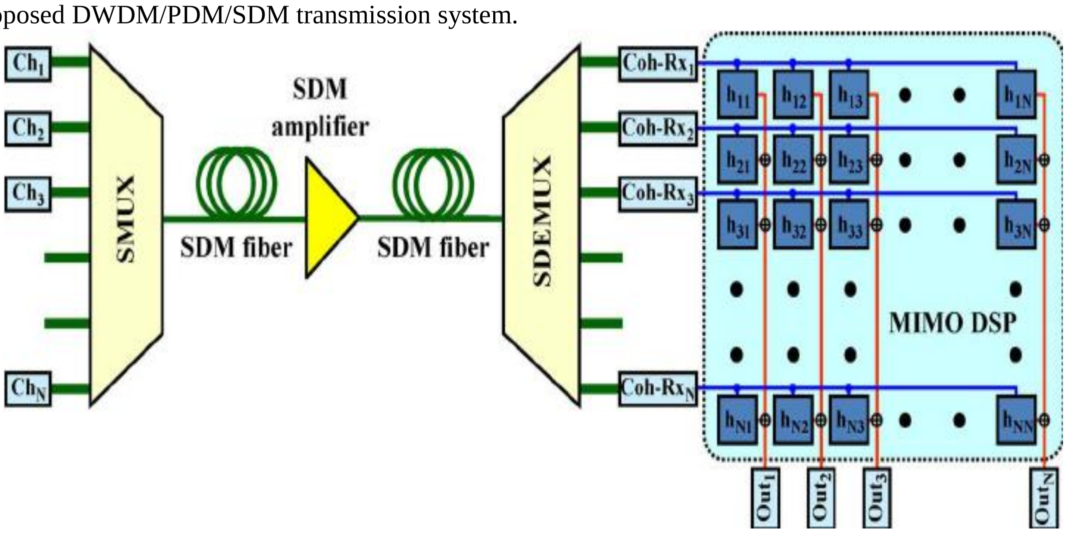


Fig.(2): Schematic of a SDM transmission system based on coherent MIMO DSP[11]

AWG (Array waveguide grating) used for multiplex and demultiplex the incoming wavelengths in each spatial mode to be modulated and dual polarized by Tx-mQAMPolMux module. Each wavelength is modulated at 40 GHz with a dual-polarization 16QAM modulation format. Multi-mode coupler used to combine input single-mode optical signals (spatial modes) into a multimode optical output signal.

The description of 8DWDM -7spatial modes SDM/PDM System can by divided into three parts:

1. Transmitter Section:

The simulated transmitter section of 7modes SDM system is presented in this section. Eight signals produced with different emission frequencies to be multiplexed by DWDM multiplexer. The transmission structure of 8DWDM -7modes SDM system consists of two parts, 8-DWDM channels transmitter and 7spatial fiber modes. The DWDM part of transmitter section used for multiplexing the incoming eight optical signals generated by LaserCW modules by using dense wavelength division multiplexing. The output signals of power splitter distributed equally into the seven spatial cores where array waveguides used to demultiplex the combined wavelengths.

The demultiplexed optical signals modulated and dual polarized by the same way as single channel system but an array of DP-mQAM Transmitter module used. This array modulated the incoming optical 8 signals with 40 GHz bit rate with specified modulation technique. Then, the eight polarization-multiplexed optical signals with quadrature modulation multiplexed again by array waveguide. Next, the seven spatial modes become ready to be transmitted over the few-mode fiber.

2. Optical fiber channel

In this section the propagation of seven spatial modes into multi-mode fiber (MMF) illustrated. MM splicer added to increase the transmission distance .Multimode ideal coupler used to couple 7 single-mode optical cores into a multimode optical fiber. The modal fields are approximated by linear polarized (LP) modes. The supported LP modes of multimode coupler(MMC) and FMF are (LP01, LP11a, LP11b, LP21a, LP21b, LP02 and LP31a) modes.Few-mode fiber in 8DWDM system has an attenuation of 0.2e-3 dBm/m and dispersion of 20e-6 s/m^2 and the slope of dispersion is 0.75e-12 s/m^3. The differential group delay values are (0, 0.05e-12, 0.1e-12, 0.15e-12, 0.2e-12) for (LP01, LP11a, LP11b, LP21a, LP21b, LP02 and LP31a) LP modes respectively, and intra Mode Group Delay (GDD) of 5e-15 s/m. Polarization mode dispersion (PMD) of multi-mode fiber is 0.05e-12/31.62 s/m. The modal fields and propagation constants calculations are performed by a separate mode solver element as indicated in single channel experiment.

Table (1) Parameters description of Multimode coupler

Coupling Matrix			
Port Number	**Mode ID**	**Magnitude**	**Phase(deg)**
1	0	1	0
2	1	1	0
3	2	1	0
4	3	1	0
5	4	1	0
6	5	1	0
7	6	1	0

3. Receiver section

The receiver section of 8DWDM 7modes SDM/PDM system is presented. Also, a bus selector module used to select the path for data traveling between optical channel and receiver section as presented in single channels system. ManyDSP techniques had been used at the receiver for linear losses compensation like MIMO, Chromatic Dispersion compensator (CD), and Carrier Power Recovery (CPR) techniques. Different channels can be tested by select the require emission frequency at optical filter and choose the channel label required at the synchronous DSP module.Dual polarization &ADC receiver parameters description is shown below:

Table (2): Dual polarization &ADC receiver parameters description

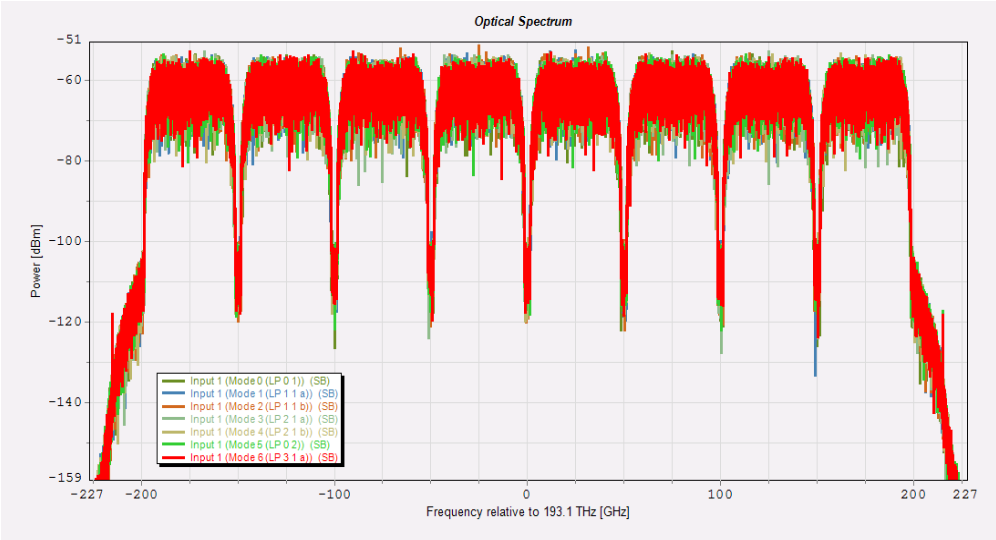
Parameter	**Value**	**Unit**
Filter type	Low pass filter	
LPF transfer function	Bessel	
Filter order	4	
ADC Sampling Rate	2*Bit rate	Hz
ADC Resolution	8	Bit

III. RESULTS AND DISCUSSION

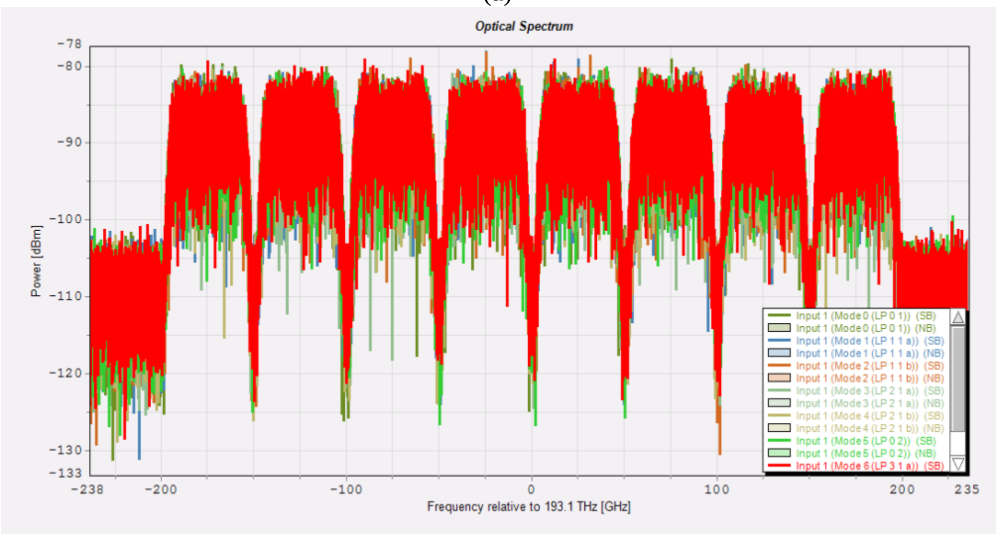
The obtained results from this system are:

i. Spectrum Result:

Figure (4-46) shows the RF scope analyzer of 8DWDM 7modes SDM PDM 16QAM system before and after 500Km distance at 40 Gb/s.



(a)

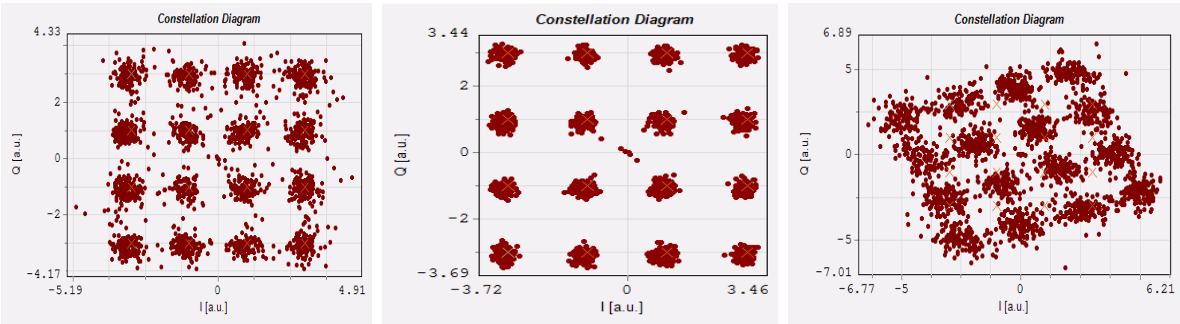


(b)

Fig.(3): The spectrum of optical OSA of 8DWDM 7modes SDM/PDM-16QAM signal (a) before and (b) after 500 km transmission distance.

ii. Constellation Diagram:

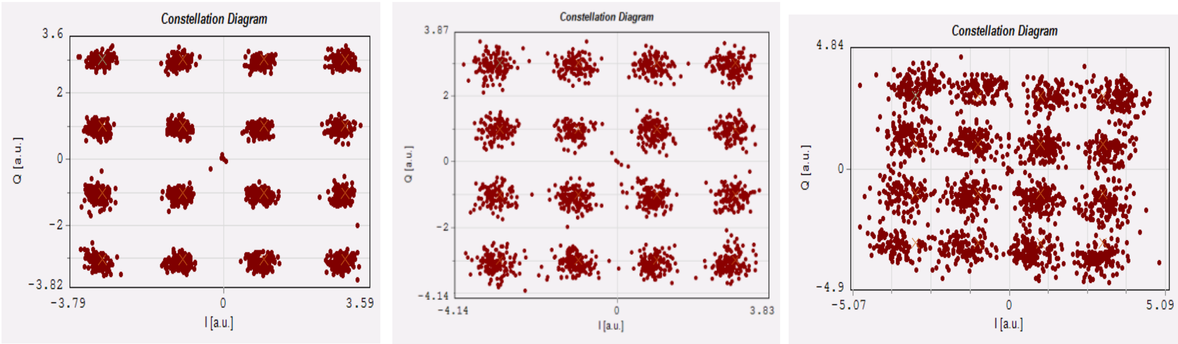
The received constellation diagrams for 400Km transmission of 16QAM system with different input power are shown in figures below. Worse constellation achieved with WDM system, which caused by the increasing of the nonlinear effects. On other side increasing the number of LP modes in FMF would increase the DGD and the nonlinear losses as a result.



(a) (b) (c)

Fig. (4): Received constellation diagram of channel 4X of LP31a mode with a. -2dBm b. 0dBm c.-2dBm at 700Km

The received constellation diagrams for 400Km transmission of 16QAM system with different length are shown in figures below. The transmission tests were obtained for a DWDM central channel (channel four) and the last LP mode of FMF (LP31a), as they practice the highest rate of nonlinearity.



(a) (b) (c)

Fig. (5): Received constellation diagram of channel 4 at LP31a mode with a. -100Km b. 0dBm c.3dBm at 700 Km

iii. Maximum reach measurements

To describe the transmission best performance of 8-channels over 7 modes SDM/PDM-1QAM system, the most extreme achieve results were measured as function of input power into the fiber and are appeared in fig.(6).

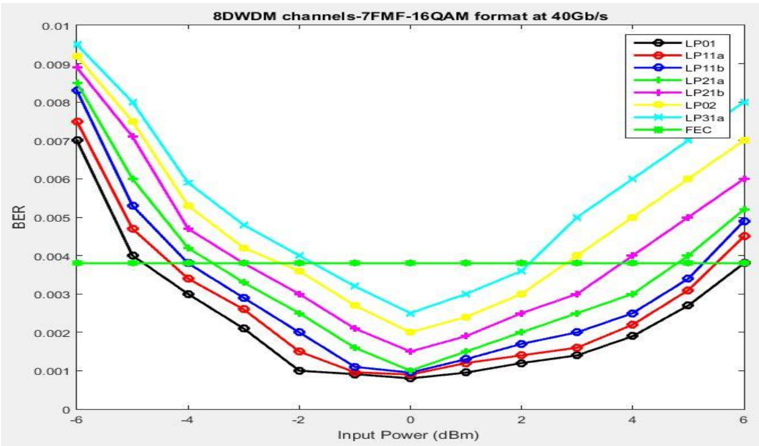


Fig.(6): Input power vesus BER for 8 channel 7modes SDM/DWDM/PDM-16QAM

The best performance of 8 channels 7 modes SDM/PDM-16QAM system and the most extreme achieve results were also measured as function of length of the few mode fiber and are appeared in fig.(7).

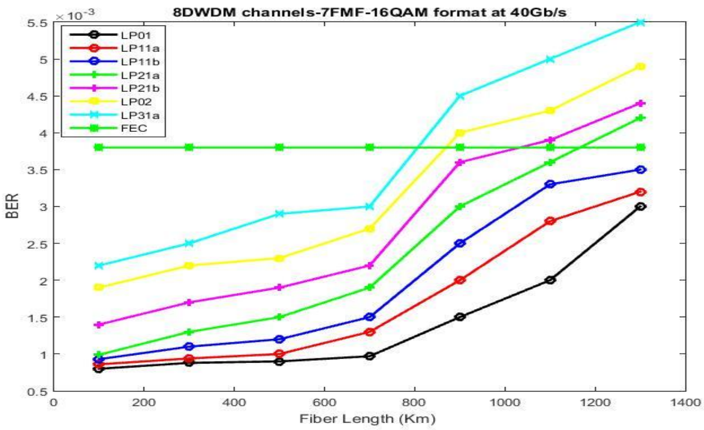


Fig. (7): Diagram of LP modes specifying BER versus length for 8 channels-7modes SDM/DWDM/PDM-16QAM system.

IV. CONCLUSION

We proposed 8-DWDM channels over 7 modes FMF system achieving a total bit rate of (2.4 THz) and the acceptable range of input power is from -1dBm to 2dBm. While the highest distance obtained is 760Km for 8-DWDM channels-7modes-SDM/PDM system**.**Several techniques used in the design of FMF transmission system including MIMO technique, CD Compensator, and Carrier Power Recovery algorithms. SDM technique showed a great advantage to achieve ultra high capacity system with high reliability and scalability.

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