

# Performance Evaluation of Advanced Modulation Formats in 5x5 Mode Multiplexed System at 800 Gbps

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**Abstract** - Multimode fibers (MMFs) paired with Linearly Polarized modes are now used for the lowest cost extended-reach interconnects over hundreds of meters and several kilometers. In this work, We have investigated the performance of different pulse shapes such as CSRZ, MDRZ and DPSK over MMF employing Laguerre-Gaussian modes in 5x5 MIMO system at 800Gbps. It is observed that for all the different Laguerre-Gaussian modes, Compressed spectrum return to zero (CSRZ) performs superior than other modulation formats. Further work extended to analyze the long reach capability of lower order modes along with higher order LG modes over 80Km stretch of MMF. System investigation and QoS also analyzed for different input powers to study the effects of mode coupling.

## I. INTRODUCTION

Explosive bandwidth demands for high speed applications are persistently increasing. This demand is consistently pushing up the efforts in designing novel schemes to meet current requirements. Fiber optic communication systems are a promising solution for these ever increasing needs. Multimode fibers are one of these approaches for realization of such high capacity Local Area Networks. These MMFs can utilize linearly polarized modes for enhancement of transmission capacity to reach maximum performance limits. To come out of this capacity crisis a number of techniques have been proposed in literature. Survey of multiplexing techniques briefs the favors and swindles discovered for respective ways. Amongst the numerous multiplexing techniques surveyed, mode division multiplexing is briskly emerging and recommended one. The MDM explores a new way to augment capacity of fiber core by transmission of numerous signals of different propagation modes on same wavelength and same core at same time. For generation of these modes, spatial optical devices are used.

Investigations at preliminary stages initiated with use of just two or three modes as LP01 and LP11 and gave results as links of 4.5 km [5] 10 km [6] 26 Km [7] 35 km [8] and 40 km [9] at adequately lower power penalties. Numerous work in past suggests use of few mode fibers [10] and MDM WDM implementations, Algorithms for MIMO signal processing and concentration on DSP in receivers etc. [11-14] to achieve maximum possible capacity and link limits.

In this Paper, we present use of advanced modulation formats for capacity enhancement of mode multiplexed system. Investigation has been performed on a 5x5 mode multiplexed system. Advanced modulation formats like MD-RZ, CS-RZ and DPSK are utilized to take the best out of capacity and link distance. The results are analyzed in terms of Q factor and thus using the drawn conclusions a high capacity system is design which operates at 800 Gbps for more than 50km.

## II. SYSTEM DESCRIPTION

CW spatial lasers tunned at 1310 nm are used for the generation of different linearly polarized modes (LP01, LP03, LP05, LP07 and LP09). Different modulation formats CSRZ, MDRZ and DPSK has been used in the system. System setup is shown in Figure and system specification are given in Table 1. Mode multiplexed data is transmitted over multimode fiber (GI-MMF) by incorporating a spatial connector.

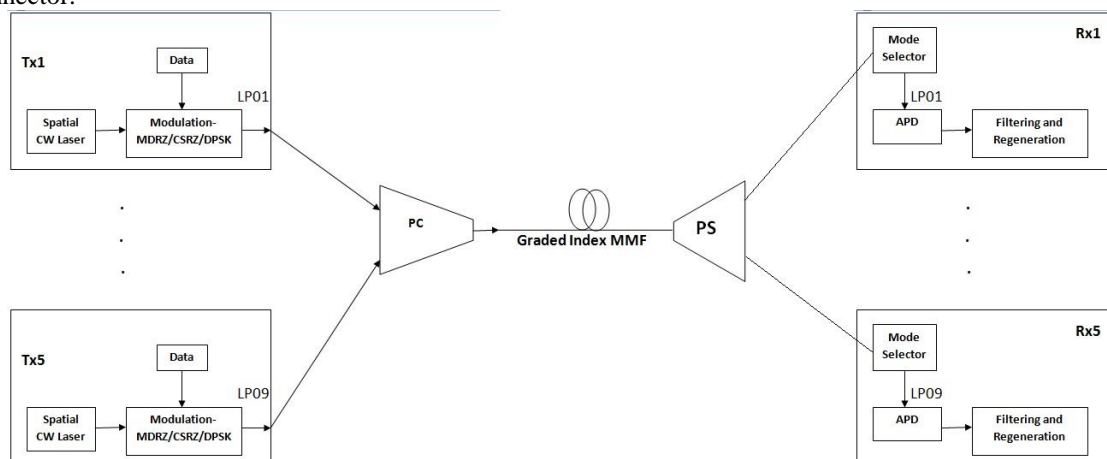


Figure.1. 5x5 Mode Multiplexed System at 800 Gbps

Multiplexed data then splitted with the help of power splitter followed by the mode selector. A PIN is used to convert the optical signal into electrical signal and then filtered by a Bessel filter. Finally system performance tested in terms of Q-factor and BER at the Eye diagram Visualizer

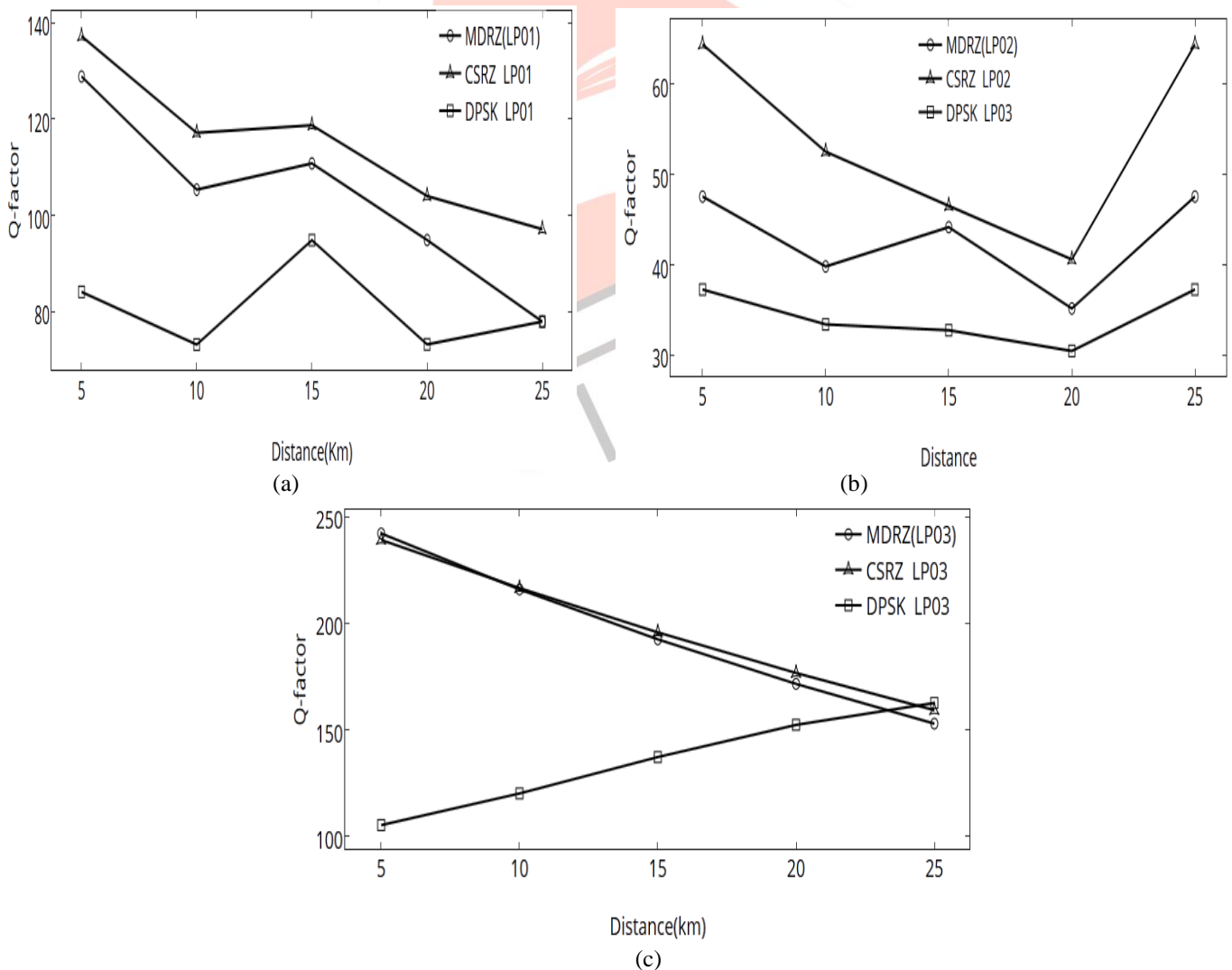
**Table.1.**System Specifications

Parameters	Values
Wavelength	1310nm
Laser Power	10dBm
Data rate	800Gbps
Fiber length	20-80Km
Core radius	10um
Clad radius	1.4142

Further a 5x5 multi input multi output has been proposed using 5 spatial CW lasers generating different linearly polarized modes. Odd modes have been taken into account for mode interleaving in order to overcome the effects of intersymbol crosstalk among the different channels. The 5x160 Gbps data transmission using graded index multimode fiber over 50 km optical link system setup requires a MIMO system which is further coupled to a multimode mode fiber using multimode coupler. The system also includes design and simulation of optical coupler along with bending induced coupler. Each transmitter consist of continuous wave laser source, a binary source have bit rate of 160Gbps bits/sec, CSRZ driver, a differential MachZander modulator .

**III. RESULTS AND DISCUSSION**

This section evaluates and compares the performance of advanced modulation formats for 5x5 mode multiplexed system over MMF. Comparison of LP01-LP03 mode profiles over MMF for MDRZ, CSRZ, DPSK has shown in Fig.2. From readings of Q-Factor it becomes clear that CSRZ is best among the three with highest values of Q-Factor when simulated at different distances for all the LG modes. Figure.3. Represents LG mode profile for LP01 LP02 LP3 respectively. Further demonstration of 800 Gbps 5x5 mode multiplexed system has been done. Performance of system has been analyzed at different input power for odd LG modes LP01 LP03 LP05 LP07 LP09. Figure.5. Shows the graphical representation of odd at varied power.



**Figure.2.**Evaluation of MDRZ,CSRZ and DPSK for (a) LP01 (b) LP02 (c) LP03

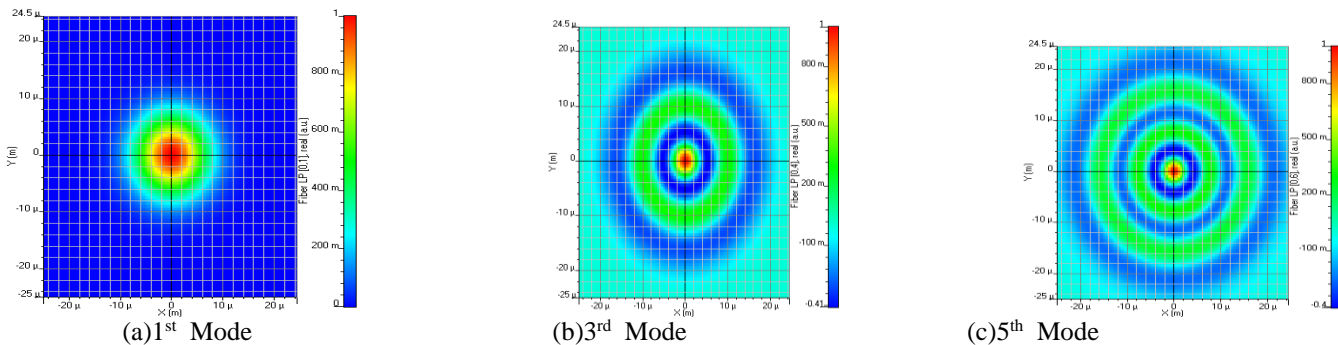


Figure.4.LG Mode profiles of 1<sup>st</sup>, 3<sup>rd</sup> and 5<sup>th</sup> Mode

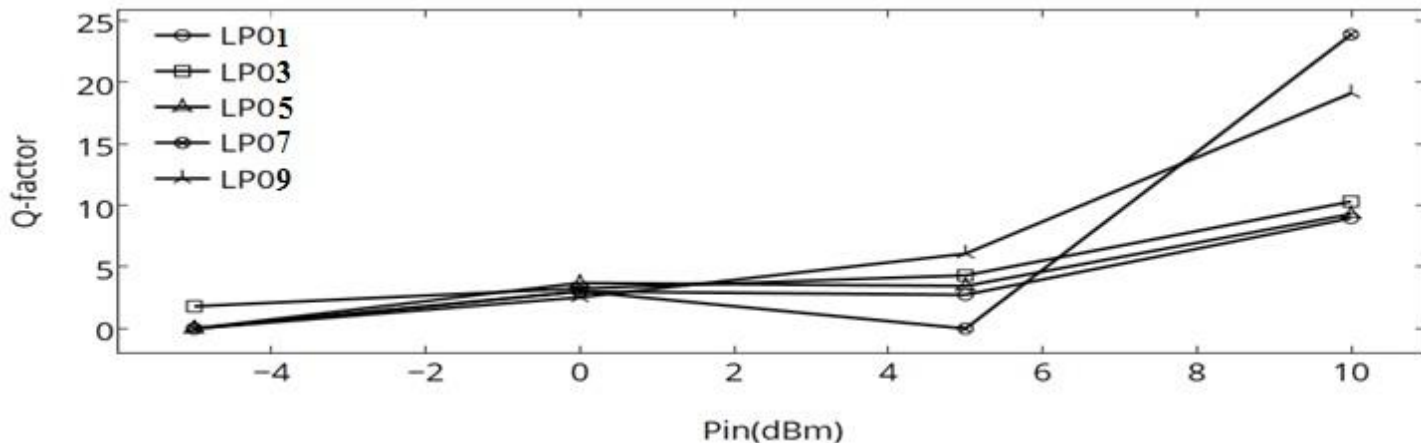


Figure.5. Graphical representation of 5x5 MDM system at varied power.

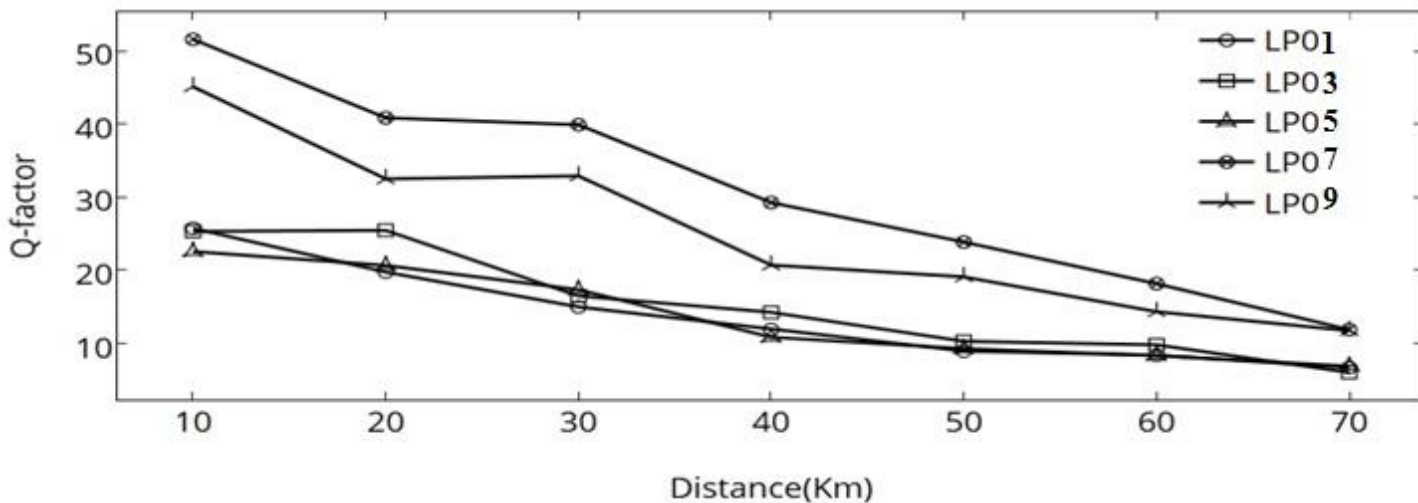
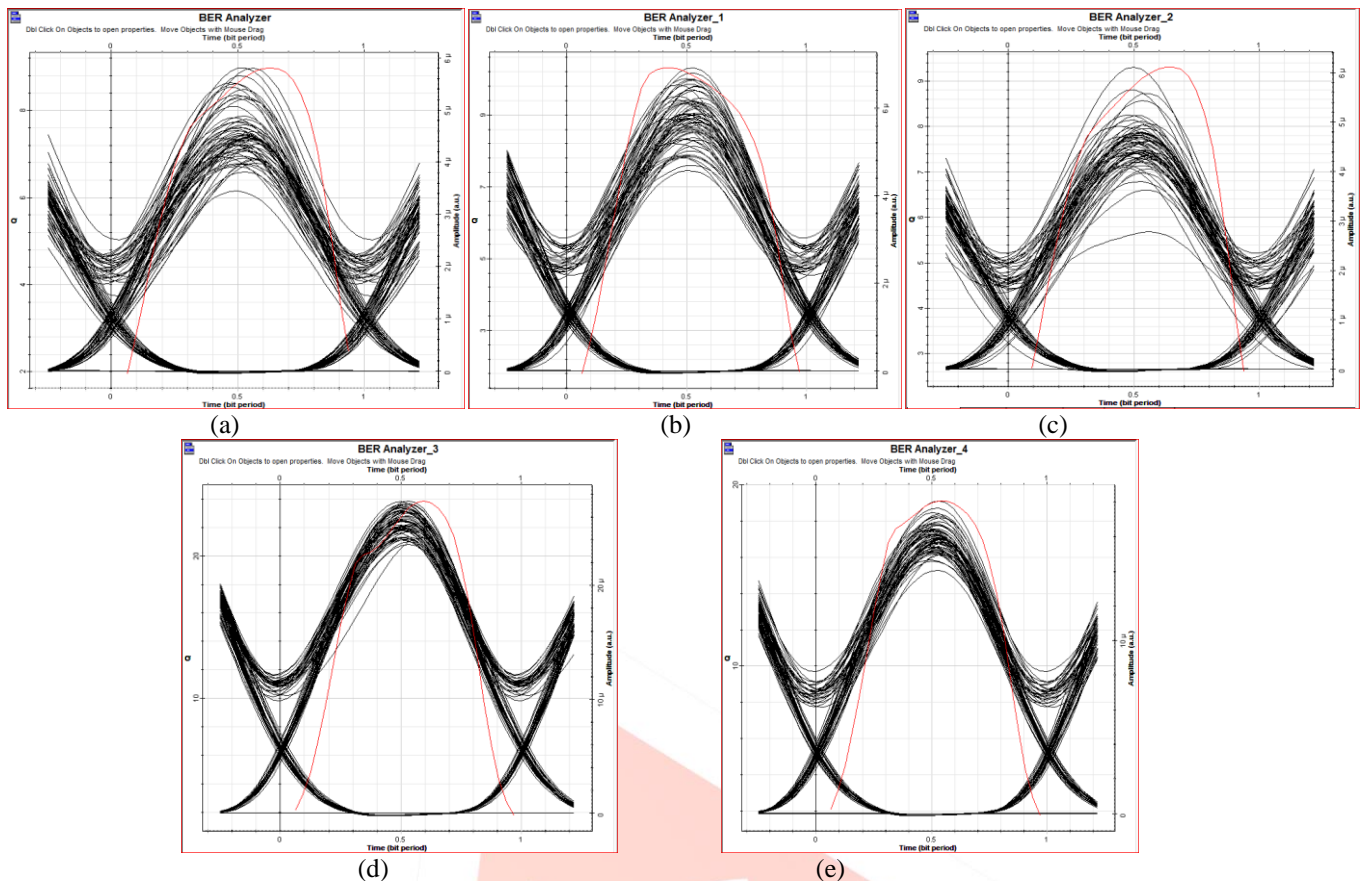


Figure.6. Graphical representation of 5x5 MDM system at varied distance.

The plot in figure 5 shows relation of distance vs Q factor for LP01, LP03,LP05, LP07 and LP 09 modes. It can be observed from graph that as distance increases the Q factor decreases however higher order modes performs better than lower ones and are recommended for use when distance requirement is increased.LP04 LG mode performs best in this system and suitable for long reach LAN's.



**Figure 7**-Evaluation of Eye diagrams at 10 dBm for (a)LP01 (b) LP03 (c) LP05 (d) LP07 (e) LP09

The above eye diagrams make it clear that Quality of received signal increases as the input power of system is increased and also that performance of higher order modes is better than lower order modes. Eye diagram of system using LP04 mode is experiencing less power penalty and eye closer.

#### IV. CONCLUSION

To accomplish increasing need for data transport mode division multiplexing(MDM) or SDM with MMF link were successfully investigated for mode multiplexing/demultiplexing up to nine modes with mode division multiplexed transmission in this work. Also performance of different pulse shapes has been investigated for 800Gbps MMF system. It is observed that CSRZ is most suitable format to enhance the system capacity and transmission distance. The result shows that at the data rate of 160Gbps/channel, the maximum fiber length with 5x5 MIMO system is up to 60km with a BER of  $10^{-9}$ . As the data rate and input power increases the intermodal coupling cause power transfer from one modes to another inside the MMF. The results also shows that maximum optical fiber link reduces to 50km at the data rate of 200Gbps/channel.

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