VCSEL-Based Multi-Mode Fiber Optical Links
for 100Gbit/s Transmission: Advanced Simulation Tools and Experimental Link Studies

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Ever since the first successful demonstration of the fiber-optic systems in 1977, commercial systems have been using multimode fibers (MMF) for short reach applications as the preferred medium of transmission due to their relative ease of use compared to the single-mode fibers (SMF). In short reach applications such as the datacenters, the constraints due to the cost and complexity of deployment drive the choice of associated technology. VCSEL-based MMF optical links offer a cost-effective solution to the growing demand for bandwidth today with the IEEE 802.3 standards group evolving constantly to address the increasing data rate requirements. Thus, advanced multi-level signaling techniques that can pack more bits per symbol need to be explored and implemented in VCSEL-MMF links for achieving speeds > 100Gbit/s. At such higher speeds with tight power budgets, optimum link designing calls for a thorough understanding of the penalties due to the impairments. Hence, advanced modeling tools indispensable. This research aims at addressing the two aspects mentioned above:

1) A thorough understanding of the individual impairments and their temperature dependencies that are not well-understood for current optical links, but are important for future VCSEL-MMF links with speeds approaching 100Gbit/s. In particular, for VCSEL-MMF links using multi-level modulation schemes such as PAM-4, the mode partition noise (MPN) penalty can be a major limiting factor for the link reach, thus making it critical to model it accurately.

This work attempts to develop a physical yet simple model for estimating MPN penalty accurately in multi-transverse mode VCSEL-MMF links.

2) PAM-4 based optical links that can achieve > 50Gbit/s speeds with minimum signal processing. Statistical analysis of PAM-4 based multimode fiber (MMF) links is presented using VCSELs at 850nm and 1050nm across a wide range of fiber profiles with EMBc spanning from 2GHz.km to 10GHz.km. Error-free transmission of 51.56Gbit/s is demonstrated over a set of standard OM3 and OM4 fibers up to reaches of 150m with no error-correction (FEC) and 300m at FEC-conformed BER using 850nm and 1050nm VCSELs. Fiber penalties are extracted at BER ~ 10^{-12} for the set of OM3, OM4, and the WBF tested and results are compared for 850nm and 1050nm links, providing insights into the advantages and challenges in moving to longer wavelengths for bitrates > 50Gbit/s using PAM-4.

In addition, plastic optical fiber (POF) based VCSEL-MMF links and the impact of electronic equalization on them is also analyzed for 25Gbit/s and higher speeds