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Optimization of Launch Conditions in 10 Gb/s Links Using Next Generation Multimode Fibers

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Optimization of Launch Conditions in 10 Gb/s Links Using Next Generation Multimode Fibers

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Abstract — **In this letter we explore the optimization of the ISI penalty and its correlation with various transmitter and fiber parameters characterizing 10 Gb/s 300m long LAN links using 50 μm next generation multimode fibers. The analysis of a large statistical sample suggests that the range of optimal values for the laser encircled flux is 12-16 μm, the lateral offset of the source 10-18μm and the axial offset -60 to +60 μm. The optimization of the launch conditions may reduce the ISI Penalty by as much as 0.7 dB. The axial offset between the laser and the fiber axes has detrimental effects on the performance of the link if the launch conditions are not optimized.**

Index Terms—**Optical Communications, 10 Gigabit Ethernet, Next Generation MMF, VCSEL, Inter-Symbol Interference, Differential Modal Delay, Encircled Flux.**

I. Introduction

FOLLOWING historical trend to standardize links comprised of short wavelength (850nm) sources and multimode fibers in multi-gigabit Local Area Networks (LAN), like Ethernet and Fibre Channel, the IEEE 802.3ae standard, also known as 10 Gb/s Ethernet [1], included a Physical Media Dependent layer for distances up to 300m over next generation 50 μm MMF (NGMMF). The specifications for this fiber [2], along with the corresponding measurements of the laser encircled flux (EF) [3], and fiber differential mode delay (DMD) [4] were developed by the Telecommunication Industry Association (TIA). This development of the NGMMF was aided by round robin measurements and the creation of a MMF link model and simulation tool, which is described in detail in [5, 6]. The block diagram of a typical link is shown on Figure 1.

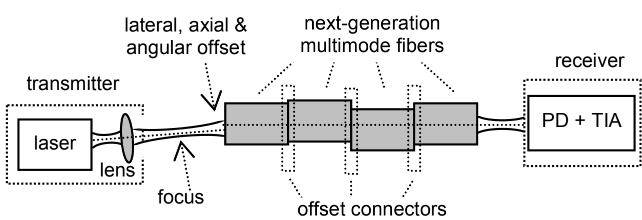

Fig. 1. 10 GbE MMF link. The number of fibers and length of each fiber depends on the link type [6].

The simulations included a large number of randomized source-fiber combinations. A link is counted as a failure if the ISI Penalty exceeds its allocation in the power budget (in this case 2.5 dB). The ISI failure rate (FR) is defined as a fraction of all otherwise TIA compliant links that failed and indicates bit error rate (BER) may be below the expected performance (BER<10^{-12}) if all the other penalties are at its limit; it does not mean link outage.

In some transceiver designs the axial misalignment (defocus) is intentionally introduced to achieve smaller laser reflection induced intensity noise (RIIN), coupling efficiency insensitive to lateral misalignment, and meet eye safety requirements. To explore the effect of intentional defocusing or axial misalignment errors, we fixed the axial offset (along the optical axis) between the laser beam waist and the fiber input face to -100, -50, 0, 50 or 100 μm, while the other parameters were as in [6].

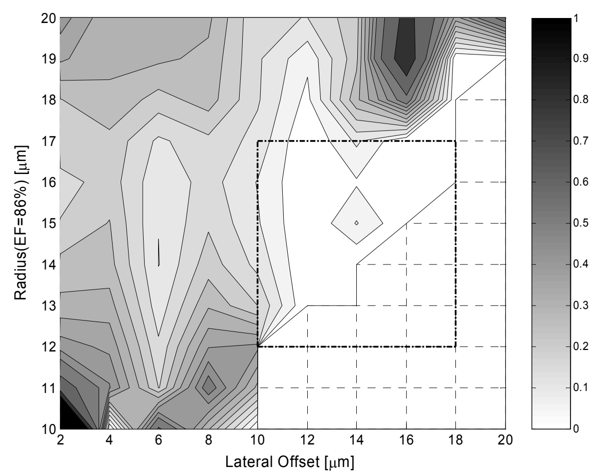

Fig. 2. ISI Failure Rate (FR) vs. lateral offset and radius of 86% EF. The magnitude of the ISI FR is coded in gray scale, with darker gray corresponding to higher values. The ISI FR is optimized in a rectangular region (dashed lines) whose boundaries are between 12 and 17 μm for the radius of 86% EF and 10 and 18 μm for the lateral offset. The ISI FR at the "hot spot" within the optimal region, at lateral offset = 14 μm and radius of 86% EF=15 μm, is only 0.1%.

Fig. 2 shows a contour plot of ISI FR as a function of lateral offset and radius of 86% EF, suggesting optimal values for the lateral offset between 10 and 18 μm, and between 12 and 17 μm for the radius of the 86% EF. As the radius of the EF gets closer to 20 μm, "hot spots" appear with increased probability of link failure, since more power is launched into

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higher order modes, which have larger propagation delays. Similarly, very small 86% EF radius values (<12 μm) are more likely to generate higher failure rates since they tend to launch the light in only few mode groups. A slight "hot spot" is observable for 14 μm lateral offset and 15 μm of 86% EF, but the ISI FR is negligible (0.1%). Although Fig. 2 shows the averaged ISI FR over all six TIA predefined DMD masks [5], we found similar results for any mask and link configuration. Our results are consistent with the previous approaches [7] that have shown the benefits of lateral offset launch for 1 Gb /s links. However, the results presented in this letter are more general, since the laser EF is also optimized and the launch is not restricted to single mode fiber launch. Earlier measurements agreed well with our simulations [8], showing 0.7-1.0 dB improvement in the ISI Penalty.

To analyze the correlation between ISI Penalty, ISI FR and some of the design and measurable link parameters, we selected a set of 10 source and fiber parameters with the highest likelihood to affect the link performance (either alone or when combined with other parameters): lateral and angular offset between the optical axes of the laser beam and the fiber; laser spot size; radii at which the EF reaches 30% and 86%; EF values at radii 4.5 μm and 18 μm; DMD Figure of Merit (FoM) in the inner (5-18 μm) and outer (0-23 μm) region, and the overfill launch bandwidth (OFLBW) of the fiber [6].

Analysis of simulation results showed that the highest correlation coefficients (0.6-0.7) are for the parameters describing the DMD profile of the fiber, followed by the group of EF-related parameters related to the laser source characteristics and launch conditions (approx. 0.25), and the fiber OFLBW (-0.2). The high correlation coefficients of ISI FR and the DMD FoMs are result of their direct relationship to the effective modal bandwidth of the fiber. In contrast, the low correlation coefficient of the OFLBW is a result of the fact that laser launches may excite a limited number of fiber modes, and not necessarily the ones who contribute the most to the OFLBW.

The individual correlation coefficients indicate that one parameter alone is not sufficient to be adopted as specifying parameter, but when combined two or more parameters provide robust link specification with low ISI failure rate. The highest five correlation coefficients (EF at 4.5 μm and 18 μm; inner and outer DMD FoM, and OFLBW) are also measurable parameters and were selected as specification parameters for the fiber and the laser [2, 6]. The ISI FR was also investigated for links specified using only one, or a combination of two or more parameters. We selected the EF, OFLBW and DMD related parameters and created the following 11 criteria: #1 has no link requirements (all links); #2-4 impose only one requirement: EF, OFLBW or DMD; #5-7 combine two requirements: EF and OFLBW, EF and DMD or OFLBW and DMD, respectively; #8 has the complete TIA set of specifying parameters (EF, DMD and OFLBW); #9-11 impose additional (more restrictive) EF requirements.

The stem-plots on Fig. 3 (a, b) show the ISI FR for links satisfying each criterion and for all five axial offsets, shown in ascending order. Not surprisingly, the criteria without fiber specification #1 (no specification at all) and #2 (transmitter specification only) have very high ISI FR (almost 20%). While the introduction of only one fiber parameter as a specification (#3 and #4) significantly reduces the ISI FR, it also shows that the acceptable level of ISI FR may be achieved by introduction of two or more specifying parameters. It is apparent that the DMD is the dominant parameter and that it alone leads to better results than the criterion #5 (combination of two parameters: EF&OFLBW). Criterion #8 (EF, OFLBW and DMD), performs better than all previous criteria (#1-7) and results in less than 1% ISI FR, and when averaged over all axial offsets, in less than 0.5%.

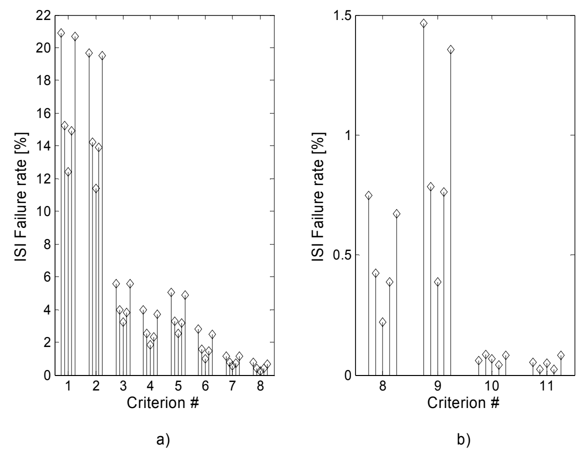

Fig. 3. ISI Failure rate for all five axial offsets (shown in ascending order) vs. various criterions: (a) criterions derived from a subset of TIA requirements (#1 -8); (b) TIA (#8) and other criterions beyond TIA requirements (#9 - 11).

Although the EF-related requirements do not improve much the ISI FR alone, they are important in reducing the ISI FR to very low values to meet the TIA requirement and optimize the link performance. This view is further supported from the impact of criteria #10 and 11, which impose additional requirement that the *r*(EF=86%) should be in the interval from 12-16 μm and 13-15 μm respectively. Criterion #9 contains only sources rejected by criteria #10, in which case the ISI FR is considerably higher (Fig. 3 (b)). Since higher order mode excitation is avoided for criterions #10 and 11, the ISI FR is very low and effectively insensitive of the axial offset over the entire range of offsets.

In the case of TIA compliant links (#8), when the axial offset exceeds 60-70 μm, the ISI FR becomes higher than 0.5% (Fig. 3b). A change from perfect focus to defocus of ±100 μm quadruples the ISI FR from 0.2% for to 0.8%. On Fig. 4 we present a statistical plot of the distribution of the ISI penalty as a function of axial offset, for criterion #8 (the plots are very similar for the other criterions). The top line of the box shows the 99 percentile, the bottom line the 1 percentile, and the * the median value of the ISI penalty distribution. An increase of 0.4 dB in the ISI penalty is observed. Wider defocusing intervals, usually required for the earlier mentioned benefits, would almost certainly fail the EF requirement, or cause high ISI FR in those links.

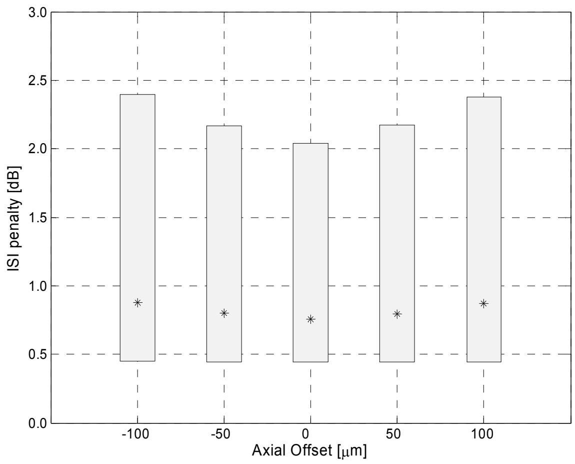

Fig. 4. Statistical plot of the ISI penalty vs. axial offset. The top line of the box shows the 99 percentile, the bottom the 1 percentile, and the * corresponds to the median of the ISI penalty distribution.

On Fig. 5 we show a statistical plot of the ISI penalty distribution for each criterion, averaged over the axial offset. The horizontal line at 2.5 dB across the figure shows the 2.5 dB ISI Penalty allocation limit. The benefits of additional EF requirements (criterion #11) to those of criterion #7 are apparent, since the ISI drops by 0.7 dB from 2.5 to 1.8 dB in 99% of the links, while simultaneously the ISI FR drops to below 0.1% (Fig. 3).

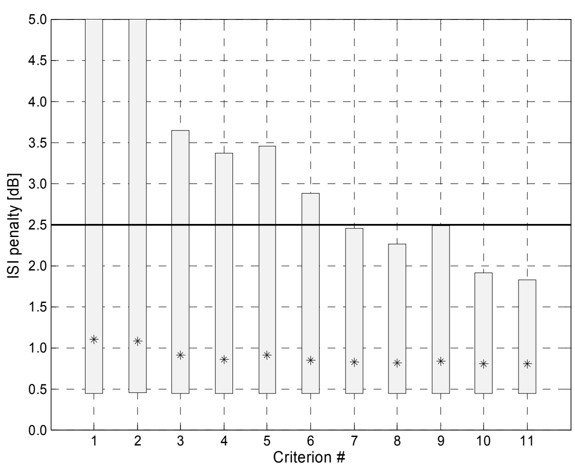

Fig. 5. Statistical plot of ISI penalty vs. criterion #. The description of the boxes is the same as in Figure 4. The line at 2.5 dB shows the ISI penalty allocation limit.

Fig. 6 shows the dependence of ISI FR on the allowed ISI Penalty in the link budget, for various criterions. Exactly 0.5% of the TIA-compliant links (#8) have ISI Penalty higher than 2.5 dB. When the links are selected according to criterions #10 or #11, the ISI Penalty allocation limit can be reduced by 0.7-0.8 dB, for 0.5% ISI FR. The increase in ISI FR is gradual and far from a cliff. The absence of the laser EF (#7) as a requirement, or the removal of its optimal values (#9) doubles the average ISI FR to 0.89% and 0.97%, respectively. It also increases the ISI FR for links with high EF sources [5, 6].

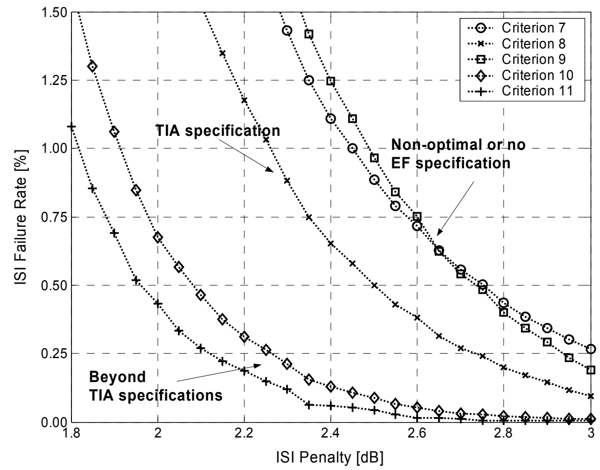

Fig. 6. ISI Failure rate vs. allowed ISI penalty for criterions #7 through #11. Links satisfy TIA DMD and OFLBW requirements, the EF is a parameter.

In this letter we explored the individual and combined impact of the measurable and design parameters on the link performance through their effect on the ISI penalty. The optimization of the laser encircled flux results in 0.7 dB reduction of the ISI penalty in 99% of these links. This decrease of ISI penalty well below its allocation limit of 2.5 dB leaves unused margin in the power budget that may be used to increased link lengths beyond 300 m, either alone or in conjunction with other techniques like link equalization.

REFERENCES

[1] IEEE 802.3ae 10 GbE standard, June 2002

[2] "Detail specification for laser optimized, 50μm core diameter/125μm cladding diameter class Ia graded index multimode optical fibers," TIA-492AAAC, 2002

[3] "Launched Power Distribution Measurement Procedure for Graded-Index Multimode Fiber Transmitters", TIA/EIA-455-203, June 2001

[4] "Differential Mode Delay Measurement of Multimode Fiber in the Time Domain", TIA/EIA-455-220, December, 2001

[5] P. Pepeljugoski, M. Hackert, J. S. Abbott, S. Swanson, S. Golowich, J. Ritger, P. Kolesar, C. Chen, P. Pleunis. "Development of Laser Optimized 50 μm Multimode Fiber for Multi-gigabit Short Wavelength LANs", IEEE Journal of Lightwave Technology, Vol. 21, No. 5, 2003, pp. 1256-1275

[6] P. Pepeljugoski, S. Golowich, J. Ritger, P. Kolesar. A. Risteski, "Modeling and Simulation of the next generation multimode fiber, IEEE Journal of Lightwave Technol.ogy, Vol. 21, No. 5, 2003, pp. 1242-1255

[7] L. Radatz, I. H. White, D. G. Cunningham, M. C. Nowell, "An Experimental and Theoretical Study of the Offset Launch Technique for the Enhancement of Bandwidth of Multimode Fiber Links", IEEE Journal of Lightwave Technology, Vol. 16, No. 3, 1998, pp. 324-331

[8] P. Pepeljugoski, S. E. Golowich: "Measurements and simulations of intersymbol interference penalty in new high speed 50 μm multimode fiber links operating at 10 Gb/s", OFC 2001, Anaheim, CA, paper WDD-40 (2001).