American Journal of Electronics & Communication

Mike Nix et al, American Journal of Electronics & Communication, Vol. I (1), 15-18

Modal noise improvement in 10-Gb/s offset launch in multimode fiber link with multimode fiber taper

Mike Nix
Department of Electrical and Computer Engineering
Queen's University
Kingston, ON, Canada

Chen Qian
Department of Electrical and Computer Engineering
Queen's University
Kingston, ON, Canada

Scott S.-H. Yam
Department of Electrical and Computer Engineering
Queen's University
Kingston, ON, Canada
scott.yam@queensu.ca

Lisa Huff
Advanced Design and Applications Data Communications Competence Center
Nexans Inc
New Holland, PA, USA

***Abstract*— Implementing the newest IEEE 802.3 Ethernet standards and updating older systems to meet those standards requires the use of laser diodes to maintain a high bandwidth-distance product through the multimode fiber link. However, due to the high coherence of such sources, link performance can be severely impaired by modal noise. In this paper the use of a multimode fiber taper to reduce modal noise in a 220 or 300 m, 10 Gb/s IEEE 802.3aq-compliant link is investigated. It was found that by inserting the taper at the input of the multimode fiber link, modal noise improvement was seen at different single-mode transverse launch offsets with a maximum signal-to-modal-noise ratio improvement of 8 dB being observed.**

Keywords*— *multimode fiber, fiber taper, 10 GbE, modal noise

I. INTRODUCTION

With many emerging applications requiring increased data transmission rates, there is interest in updating older and installing new premise and local area networks to speeds beyond 1 Gb/s. The newest IEEE 802.3 Ethernet standards (802.3ae/aq) require 10 Gb/s transmission over 220 m of 62.5/125 μm legacy multimode fiber (MMF) or up to 300 m over newer 50/125 μm laser optimized fiber [1]. There is also work being done to vastly improve the bandwidth distance product of multimode fiber beyond the current 2,000 MHz.km towards 40 Gb/s and 100 Gb/s Ethernet [2.]

Traditionally, multimode networks used low cost LEDs as a signal source due to their low cost, but for the new Ethernet standards the modulation bandwidth of an LED is far too low. As a result, laser diodes (LD) are being used in the newer MMF systems [1, 3-5]. However, because of the high coherence length of LDs compared to LEDs, a significant problem can arise: modal noise [6, 7]. Modal noise is due to a dynamic interference pattern between different transverse fiber modes caused by low frequency fiber fluctuations with a source of mode-selective loss (MSL) located somewhere in the fiber link. This mode-selective loss is usually due to connector offsets and it essentially filters out specific fiber modes. If the interference pattern is changing, different modes are being filtered by the MSL, and this results in power fluctuations that are ultimately seen at the receiver as noise on the signal [6, 7].

Previous work has demonstrated the ability for a fiber taper to improve MMF link performance by spatially filtering higher order modes [8]. However, it is not clear how this type of MSL will affect modal noise. In this paper, we investigate the effect of fiber taper on modal noise in systems employing coherent laser and laser optimized MMF links. By selectively removing higher order modes with significantly different group delays than lower order modes at the input of the MMF links, signal-to-noise ratio due to modal noise sees dramatic improvement from 2 to 8 dB at different offset launch positions. Thus, a simple and low-cost device could potentially relax the design specification for electronic dispersion compensation (EDC) integrated circuits for short reach MMF applications.

II. EFABRICATION OF MMF TAPER

A multimode fiber taper can be fabricated by slowly stretching a length of multimode fiber while simultaneously applying a strong heat source at a single point. For the taper to be ideal, it should be stretched sufficiently slowly so that it has a consistent shape along its length and low optical power loss. Assuming an exponential taper model9, the taper waist, d, is found to be $d = D_0 \exp\{L/L_0\}$ where D_0 is the original fiber diameter, L_0 is the length of the taper waist region and L is the length of the region of exponential decrease. Using a flame as a heat source, the length of the taper waist region, L_0, is solely determined by the width of the flame.

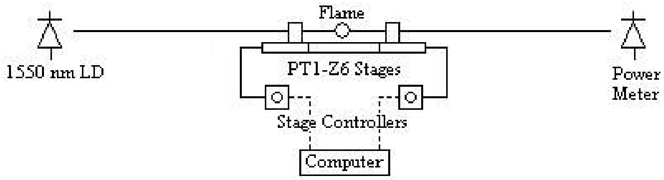


Fig. 1: Taper Fabrication Setup

To fabricate the taper, a propane burner and micro torch kit with a flow controller was used where the flame temperature reaches approximately 1800 ℃ and the flame width was set to be 4 mm. Two computer-controlled Thorlabs PT1-Z6 motorized stages with fiber clamps were used to stretch the fiber at a translational speed of 0.3 mm/s. During the fabrication process, a 1550 nm laser diode and power meter was used to continuously monitor the insertion loss through the taper. Fig. 1 shows the taper fabrication setup.

After many trial fabrications a taper waist of five microns was decided on. This waist provided the taper with a low optical loss (< 1 dB) while allowing for easy fabrication with a high degree of repeatability.

III. GENERATING MODAL NOISE

For modal noise to be present in a multimode fiber link, the modal interference (or speckle) pattern present at the receiver has to be dynamically changing. This can be due to either low frequency vibrations present along the link or due to laser instability at the transmitter. A dynamic interference pattern itself does not cause modal noise because if enough modes are excited the received power will remain relatively constant. However, if there is a source of mode selective loss (such as offset connectors) that selectively filters out certain modes in the link, then the dynamic interference pattern will also result in dynamic power fluctuations.

To generate the modal noise in the multimode fiber link under test, the procedure described in TIA FOTP-142 [10] was followed. The mode selective loss generator was constructed from a 10 m long piece of multimode fiber. Located along the fiber, at 2, 6, and 10 m three mode selective loss locations were placed. Each one of these connections consisted of an offset splice such that there was 1 dB loss across the splice and the total loss through the mode selective loss generator approximately 3 dB. To create the dynamic modal interference pattern, a 10 m length of fiber was coiled into a figure-eight configuration and then placed on an electric shaker such that as the shaker vibrated the fiber was flexed back and forth. The mode selective loss element combined with the fiber shaker allowed for the generation of modal noise in the multimode fiber link under test.

IV. EXPERIMENTAL SETUP

To measure the modal noise penalty of our multimode fiber link, the procedure and test setup as described in TIA FOTP-142 [10] was used to generate the MSL element and modal noise. All components used and measurements taken conform to this test procedure. Fig. 2 shows the final experimental setup. A 1550 nm laser diode with a 100 kHz line-width was used, although other wavelengths can be used as well. The Mach-Zehnder modulator (MZM) intensity modulated the output of the LD and the EDFA was used to compensate link loss and allow for meaningful measurements. The modal noise mechanism (MNM) in Fig. 2 consists of four elements arranged in five different configurations: A) 10 m fiber shaker, 10 m reference fiber; B) 10 m fiber shaker, 3 dB MSL; C) 10 m fiber shaker, 3 dB MSL, MMF Taper; D) 10 m fiber shaker, MMF Taper, 3 dB MSL; E) MMF Taper, 10 m fiber shaker, 3 dB MSL; where the MSL and fiber shaker are constructed as detailed above. The offset launch was done using a single mode fiber (SMF) aligned with a MMF using a six-axis nano-positioning stage with 37.5 nm resolution and 30 nm x-/y-/z-axis repeatability. To maintain offset accuracy, the stage was reset and homed after each measurement set. The transverse offset range was 0 – 24 μm from the MMF center axis in 2 μm steps. The taper was a 50/125 μm graded-index MMF tapered down to a diameter of 5 μm, with a measured insertion loss of only 1 dB as detailed above. The fiber under test (FUT) consisted of either a 220 or 300 m MMF made from the same preform. The optical receiver is MMF pigtailed with a bandwidth of 9 GHZ and the oscilloscope (OSC) used had standard compliant bandwidth of 12 GHz [10].

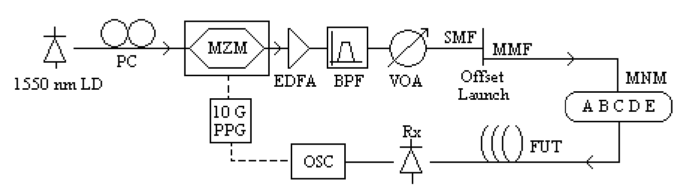


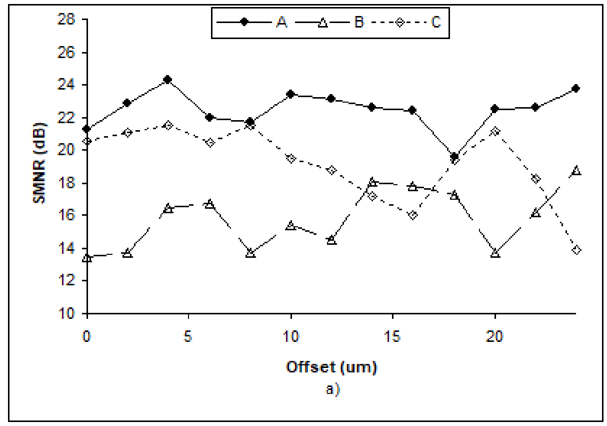
Fig. 2: Experimental Setup.

V. MEASURING MODAL NOISE

Using one of these ten configurations (A/B/C/D/E and 220/300 m FUT), the 10 m fiber shaker was set to oscillate at 8 Hz to create the modal noise in the link. To measure the amount of modal noise present in the link, FOTP-142 [10] was again followed. The modulator was set up to generate a simple periodic bit sequence of alternating ones and zeros. The optical signal was then received and the electrical signal viewed on the oscilloscope. For ease of comparison, the output was then measured and the attenuator (VOA) was changed for each sample and transverse offset so that the peak-peak output voltage measured by the oscilloscope was 20 +/- 1 mV. The oscilloscope was then set up so that a voltage histogram measured a "1" or "0" value at the midpoint of the bit period where the modal noise distribution was assumed to be Gaussian with bin sizes of approximately 0.16 mV. The mean and standard deviation of the histogram were then measured, and the signal-to-modal-noise ratio (SMNR) was calculated using SMNR = 20 log (μ/σ), where μ is the mean value of the "1" and σ the standard deviation. This method was also used to collect data from the received "0". To ensure just modal noise was being measured, the output of the EDFA was filtered and the noise contribution of the pre-link configuration was found as above (which was insignificant) and then subtracted from the actual measurements. These measurements were taken for each of the ten possible configurations at lateral offsets ranging from 0 – 24 µm.

VI. Results and Discussions

Fig. 3 shows the SMNR of the received signal for a MMF length of 220 and 300 m for the first three configurations (A-C), and fig. 3 shows the SMNR for the last two configurations (D, E) compared to the reference fiber (A). Figs. 3 and 4 show just the "1" data; the data for the "0" points showed similar behaviour but were omitted for the sake of brevity. To compare the results between configurations, configuration A is considered to be the best case because there is no significant source of MSL (and thus very little modal noise), while configuration B is the worst case because it consists of just the MSL. Since the MSL is the center for modal noise generation6, it was thought that placing the fiber taper after the MSL would have an effect on the modal noise. From Fig. 3, it can be seen that for 220 m the fiber taper (configuration C) generally improves the SMNR of the signal by at least 4 dB up until an offset of 14 µm. For the longer 300 m fiber there is only significant noise generated by the MSL for the middle offset range (10 – 14 µm) and there is improvement of almost 8 dB over that range. Comparing Fig. 4a to those shown in Fig. 3a, there is about 2 – 4 dB of SMNR improvement over the case with just the MSL (B) for the lower offset range (0 – 14 µm) with the 220 m fiber. For the 300 m MMF fiber, there is again only improvement seen for the middle offset range when compared to configuration B. That there is improvement for configurations D and E is an interesting result because they both have the taper placed before the MSL, which is the center for the creation of the modal noise. This in turn suggests that the use of a fiber taper at the beginning of an actual MMF link could be used to improve the total modal noise performance.



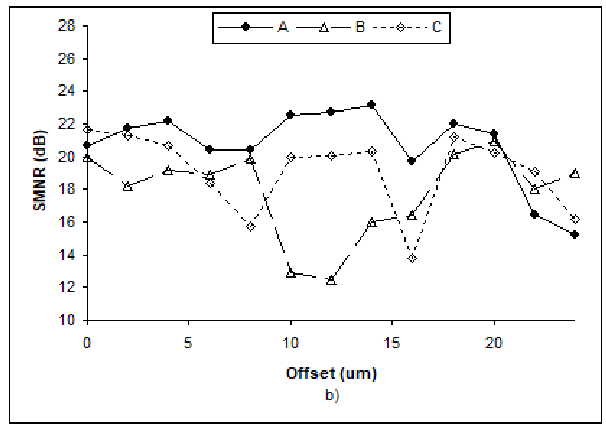
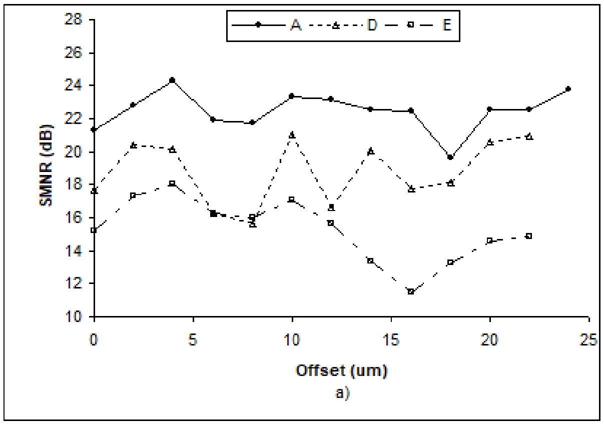


Fig. 3: SMNR results for configurations A, B, C with a) 220 m and b) 300 m MMF length.

To determine the repeatability of the measurements, data was collected at different transverse offsets for a continuous wave input and it was found that 90% of the 408 measurements taken fell within ±10% of the mean value for each offset. This level of repeatability is assumed to hold for the pulsed input case as well. During the experiment it was also found that the taper insertion loss changed with transverse offset. For the 200 m link the loss was 1 dB up until a 16 µm offset where it increased to almost 2 dB. For the 300 m link the loss was almost 7 dB for low offsets, reducing to 1 dB again for the middle offset range (10 – 14 µm).



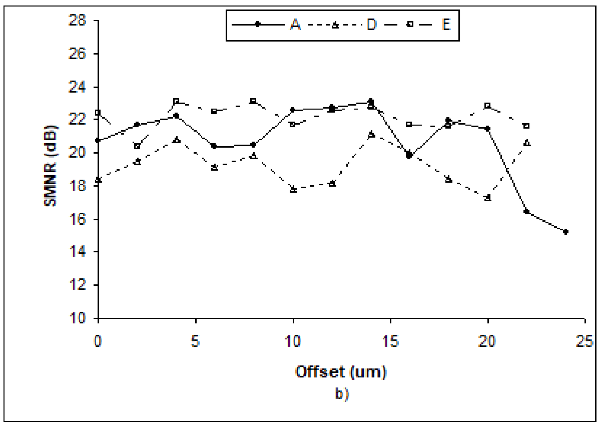


Fig. 4: SMNR results for configuration A, D, E with a) 220 m and b) 300 m MMF length.

The presence of insertion loss through the fiber taper as well as previous work [8] indicates that the taper acts as a modal filter, and because of this it can be considered a source of mode-selective loss which would degrade the modal noise performance. However, since it was found that the use of a fiber taper improves performance over a range of transverse offsets, this implies that there are unknown mechanisms inherent in high-speed MMF applications. Future work studying the effects of inline fiber tapers could potentially further our understanding of modal noise with directly modulated lasers and laser optimized MMF. Even if the modal noise performance is enhanced by only a small amount, since the 802.3aq power budget only allowed for 0.2 dB of modal noise [11], a fiber taper could be used to improve performance in particularly problematic systems.

VII. Conclusions

The use of a fiber taper is a novel method for reducing modal noise and in this study we have seen the effect a multimode fiber taper has on improving performance in a 220 or 300 m MMF link. For the 220 m link it was found that placing a fiber taper before or after the source of mode-selective loss (and thus the source of modal noise) resulted in an improvement in signal-to-noise ratio of 2 – 7 dB for a transverse launch offset up to 14 μm when compared to a purely MSL configuration. A link length of 300 m showed significant noise generation for a launch offset of 10 – 14 μm and a maximum SMNR improvement of 8 dB was observed. Because placing a fiber taper at the input of a MMF link improves performance, a fiber taper could be used as an effective, easy to deploy and very inexpensive enabling component in high bit-rate MMF Ethernet applications.

References

[1] P. Ronco, J. Abbot. "10 Gb/s Solutions for Multimode Fiber Premises Networks." Corning Optical Fiber Guidelines. Vol. 13E, 2006.

[2] Yam, S. S-H., Achten F. "Toward 100 Gbits/s Ethernet with Broad Wavelength Window Multimode Fiber." J. Optical Networking. 6(5), 527-533 (2007).

[3] Papen, G. C., Murphy, G. M. "Modal Noise in Multimode Fiber under Restricted Launch Conditions." J. Light. Tech., 17(5), 817-822 (1999).

[4] Webster, M. et al. "A Statistical Analysis of Conditioned Launch for Gigabit Ethernet Links Using Multimode Fiber." J. Light. Tech., 17(9), 1532-1541 (1999).

[5] Wegmuller, M. et al. "Evolution of the Beam Diameter in a Multimode Fiber Link Through Offset Connectors." IEEE Phot. Tech. Letters, 13(6), 574-576 (2001).

[6] Epworth, R. E. "Modal Noise – Causes and Cures." Laser Focus with Fiber Optic Technology. 109-115 (1981).

[7] Pepeljugoski, P. et al. "Modal Noise BER Calculations in 10-Gb/s Multimode Fiber LAN Links." IEEE Phot. Tech. Letters, 17(12), 2586-2588 (2005).

[8] Moon, S. and Kim, D. Y. "Effective Single-Mode Transmission at Wavelengths Shorter Than the Cutoff Wavelength of an Optical Fiber." IEEE Phot. Tech. Letters, 17(12), 2604-2606 (2005).

[9] Kenny, R. P., Birks, T. A., Oakley, K. P. "Control of Optical Fiber Taper Shape." Electronics Letters, 27(18), 1654-1656 (1991).

[10] "Measurement of modal noise power penalty for laser sources." FOTP-142, TIA/EIA SC FO-5.6, 6/14/99.

[11] Cunningham, D. et al. "Modal Noise and Implications for the CSRS Test." Presented at the IEEE P802.3aq 10GBASE-LRM Task Force meeting, March 2006. [Online]. Available: http://www.ieee802.org/3/aq/public/mar06/cunningham_1_0306.pdf

[12] Couch, P. R., Epworth, R. E. "Reproducible Modal-Noise Measurements in System Design and Analysis." J. Light. Tech. 1(4), 591-596 (1983).

[13] Epworth, R. E. "The Phenomenon of Modal Noise in Fiber Systems." in Proc. Topical Meeting Opt. Fiber Commun. (1979).