# TRANSMISSION CAPABILITIES OF LARGE CORE GI-POF BASED ON BER MEASUREMENTS

P. Heredia (1), J. Mateo (1), M. A. Losada (1)
1: GTF, Aragón Institute of Engineering Research (i3A), Department of Electronic Engineering, University of Zaragoza, María de Luna 1, 50018 Zaragoza, Spain.
Phone: +34 976 762360. Fax: +34 976 762111. E-mail: jmateo@unizar.es

**Abstract:** *In this work we characterize the transmission capabilities of several plastic optical fibers with a bit error ratio measurement system by sweeping the data rate. The data rate limit at each fiber length can be extracted from these measures and, used jointly with the eye diagrams, allows us to assess the capabilities of each fiber. From the conclusions obtained by analyzing these results, we will be able to propose a technique to improve the overall fiber-transceiver performance.*

## 1. Introduction

POF technology has lately attracted a lot of interest in data transmission for local area networks (LANs) such as those for office or home applications [1]. Large core PMMA fibers have been an attractive solution for industrial and home deployment because their ease of handling due to their large cores, their robustness under bending, and their use with visible light. Nowadays, with the increase of multimedia home applications, broadband transmission media are needed and graded-index plastic optical fibers (GI-POFs) have arisen in the market. These GI-POFs permit to increase transmission distance at high data rates, while the 1mm-core-diameter PMMA GI-POFs still keep the traditional advantages of the step-index POFs (SI-POFs). However, high speed detectors working in the visible region of the spectrum are scarce in the market. There are several research groups working in the design of this kind of transceiver but they are still in a pre-commercial stage [2].

Here, we propose a method based on the estimation of Bit Error Rates (BERs) to assess the overall behavior of large-core PMMA GI-POFs and to compare them with conventional SI-POFs. For our set-up, we have used commercially available transceivers that are not specifically designed for gigabit data rates. Thus, the main goal of our paper is to assess the overall behavior of different types of fibers from different manufacturers by measuring the BER versus data rate. An analysis of our results will permit to determine the application boundaries for each fiber type. In addition, we investigate the interface fiber-transceiver to devise a technique to improve the data rate suggested by our research on fiber power diffusion [3].

The paper is organized as follows: First, we describe the tested fibers, the used devices and the experimental set-up to obtain BER versus data rate and the eye diagrams. Next, we show our measurements for the different fibers and lengths. Then, we analyze our results to assess the propagation properties for the fibers tested and the effect of the displacement of the fiber inside the transceiver. Finally, we summarize the conclusions derived from these results.

## 2. Experimental methods

### 2.1 Materials

We measured several 1mm-diameter core PMMA POFs with step-index profiles: A broadband fiber, the PMU-CD1002-22-E (PMU) from Toray with a relatively low numerical aperture of 0.33, the HFBR-RUS500 fiber (HFB) from HEWLET-PACKARD with a numerical aperture (NA) of 0.47 and the ESKA PREMIER GH4001 (GH) from Mitsubishi with a numerical aperture of 0.5. Finally, we also tested the OM-GIGA, from Optimedia [4], which is a 1mm-diameter core GI-POF. We want to point out that this fiber was a sample acquired in May 2005, when the product was at an early stage of production.

Table 1 shows the values of attenuation per meter for 25m and 50m of the tested fibers. These attenuations were obtained using the same electro-optical module that was used later in the BER measurement system, which will be described in the next subsection. The attenuation was intentionally measured in disequilibrium modal conditions without any scrambler to resemble final-user situations, which explains why different values have been obtained at different lengths.

Table 1: Measured attenuation of the tested fibers.

| Fiber | Length = 25m | Length = 50m |
|---|---|---|
| PMU | 0,24 dB/m | 0,19 dB/m |
| HFB | 0,14 dB/m | 0,15 dB/m |
| GH | 0,19 dB/m | 0,17 dB/m |
| OM-GIGA | 0,30 dB/m | 0,25 dB/m |

### 2.2 Description of the optical transceiver board

We designed and manufactured a transceiver board including the devices to perform the electro-optical conversion in our measurement system. The main module is the transceiver (FOT-FOR) optimized for high-speed Fast Ethernet of 125Mbps suitable for large core POFs. It is based on an EDL300E-120 (transmitter FOT) and an EDL300D-120 (receiver FOR) from

Firecomms. In fact, one of the objectives of this work is to explore the limits of this transceiver. The link to the fibers is performed by the novel OptoLock connector. The electrical input and output lines from the transceiver are brought out to SMA connectors to the pseudorandom (PRBS) generator, to the BER analyzer and to an oscilloscope to monitor the eye diagram pattern.

### 2.3 Experimental set-up

The schematic of the experimental set-up used in our measurements is depicted in Figure 1. The BER measurement system is based on the OptoBERT OPB3200 from Optellent. The OptoBERT incorporates a pseudorandom binary sequence (PRBS) generator that supports continuously variable data rates from 100Mbps to 3150Mbps. The generated signal is injected to the emitter at the transceiver board and is transmitted through the fiber. The optical receiver regenerates the signal from the optical output. The resulting BER is acquired by a computer and processed using specifically designed software that permits to record the measured BER results.

In addition to BER estimation, the measurement system incorporates the simultaneous acquisition of the corresponding eye diagrams using an Infinium DCA 86100A oscilloscope from Agilent. The oscilloscope is connected to the output of the transceiver board and is externally triggered from the clock signal from the OptoBERT.

The complete set-up simulates a transmission system with the pattern generator driving the transmission side of the POF link and an oscilloscope on the receiver side. Thus, we can evaluate the transmission characteristics of different POFs obtaining BER and eye diagrams directly by sweeping the data rates using a computer controlled system. We have obtained the BER and eye diagrams versus data rate for several lengths for each different fiber type using the described set-up.

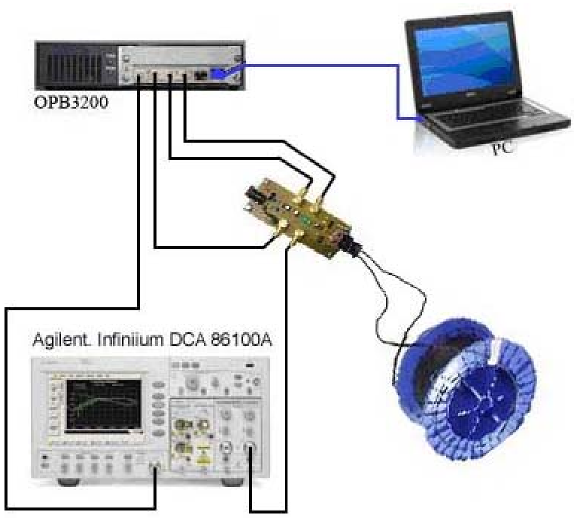



Figure 1: Schematic of the experimental set-up to implement the methods to obtain BER and eye diagrams versus transmission data rate.

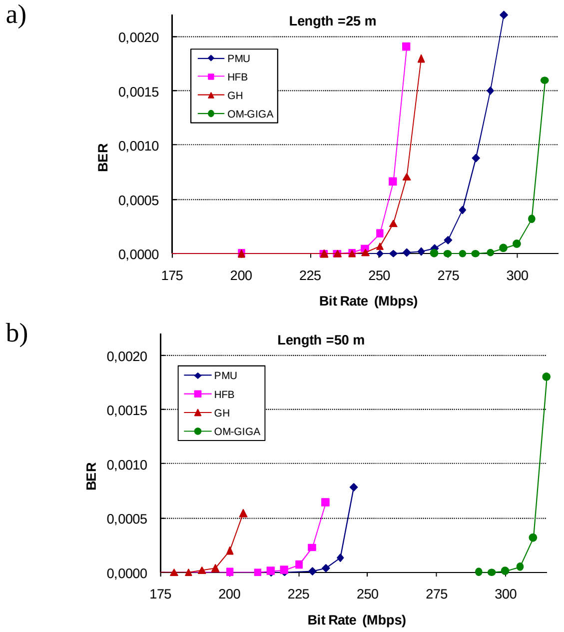



Figure 2: BER versus data rate for PMU, HFB, GH and OM-GIGA. a) Length = 25m. b) Length = 50m.

## 3. Results

### 3.1 BER versus data rate for GI-POFs and SI-POFs

The BER versus data rate in Mbps is shown in Figure 2 for 25m and 50m of the SI-POFs: PMU, HFB and GH and the OM-GIGA. Figure 2 shows a similar monotonic BER increase for all fibers and lengths. There are two different regions separated by an elbow at a different data rate for each fiber type, which is followed by a steep BER increase at higher rates. At slower data rates, the BER is constant and approximately equal to zero.

When the fiber length is 25m, the errors appear at the same rate for the two high NA fibers (GH and HFB), while for the lower NA fiber (PMU), the BER start to increase at a slightly higher rate. The values of data rates for OM-GIGA are significantly higher compared to those achieved for the other fibers. For a length of 50m, the best behavior is found for the OM-GIGA followed by the PMU, but the HFB is now significantly better than the GH.

In order to compare quantitatively the capabilities of the different fiber types, Table 2 shows the data rate allowed to get a BER less than $5 \cdot 10^{-4}$, and the absolute maximum data rate attainable for 25m and for 50m. Here, we can verify that for 25m, the maximum data rates for the GH and the HFB at a $5 \cdot 10^{-4}$ BER are nearly similar while the HFB has a much better behavior than the GH for 50m.

Table 2: Data rate for a BER = $5 \cdot 10^{-4}$ and maximum data rate attainable for 25m and for 50m, in Mbps.

| Fiber | BER = $5 \cdot 10^{-4}$ | | Max. bit rate | |
|---|---|---|---|---|
| | Length=25m | Length=50m | Length=25m | Length=50m |
| HFB | 253 | 233 | 260 | 235 |
| GH | 257 | 204 | 265 | 205 |
| PMU | 281 | 243 | 295 | 245 |
| OM-GIGA | 306 | 310 | 310 | 315 |

3.2 Performance of the OM-GIGA

The capabilities of the OM-GIGA have been assessed by measuring the BER versus data rate for two more fiber lengths of 5m and 75m, which are shown in Figure 3.

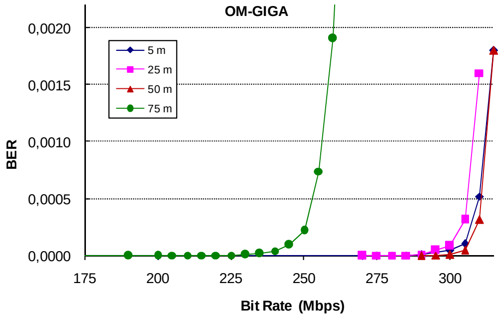
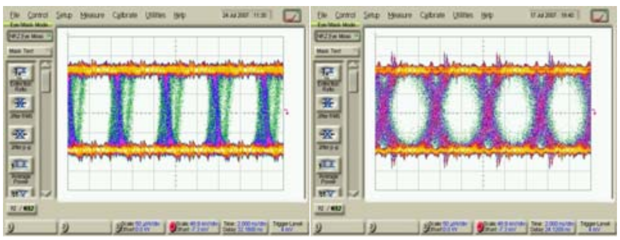



Figure 3: BER versus data rate for OM-GIGA from Optimedia for 5m, 25m and 50m fiber lengths.

Figure 3 clearly shows that the maximum data rate for lengths from 5m to 50m is limited by the transceiver, since this limit is independent of fiber length. However, for 75m, the maximum data rate decreases noticeably down to 250Mbps. The eye diagrams for the OM-Giga at 200Mbps are shown in Figure 4 for 5m and 75m to help us to justify this behavior in the next section.



a) Length = 5m b) Length = 75m

Figure 4: Eye diagrams for the OM-Giga at 200Mbps.

3.3 BER improvement by spatial filtering

As modal dispersion is mostly due to the power propagating at outer modes [3], bandwidth should increase and consequently, errors should decrease by narrowing the angular range or filtering out the power at the emitter or the receptor sides. Therefore, we assess the effects of this spatial filtering both in transmission and in reception. We have achieved this spatial filtering by slightly displacing the fiber input and output ends from the emitter and the detector respectively. Figure 5 shows the improvement produced by spatial filtering at the emitter (upper row) and at the receiver (lower row) for 25m (leftmost column) and 50m (rightmost column) of the three SI-POFs. The data rate is the maximum attainable for each fiber and each length, shown in Table 2. Notice that the data rates for 25m are higher than for 50m, which prevents a quantitative comparison of the BER improvement between lengths. Figures show that the worst BER is obtained when the fiber end is closest to both the emitter and detector. The BER remains lower for shifts of several millimeters until it rises again due to power loss, at a different separation for the different fibers.

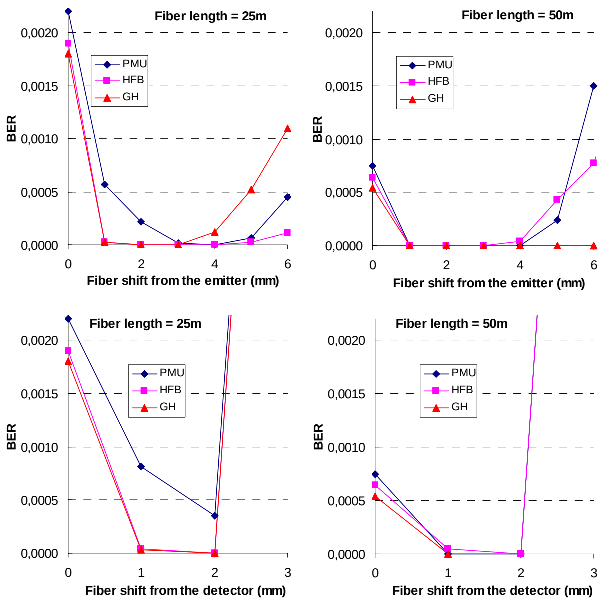
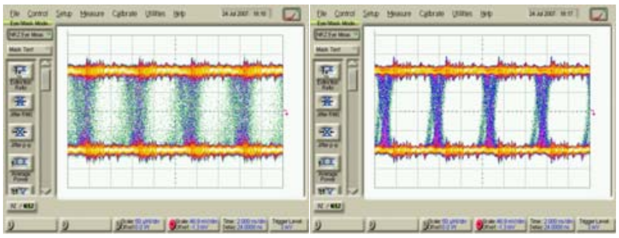



Figure 5: BER versus fiber shift from the emitter and from the detector for lengths of 25m and 50m.

When the fiber is shifted from the detector end only 1 or 2mm the BER decreases steeply. Beyond 2mm, the excess loss prevents any communication for all fibers and lengths.

To visualize the effect on the eye opening of the spatial filtering, we have recorded eye diagrams. Figure 6 shows the eye diagrams for the GH fiber at a data rate of 200Mbps close to the emitter (a) and shifted 1mm from it (b).



a) Fiber close to emitter b) Fiber at 1mm from emitter

Figure 6: Eye diagrams for a GH fiber of 50m at 200Mbps.

Although the same experiments were performed for the OM-GIGA, data is not presented here because there was no improvement by displacing any of its ends.

## 4. Discussion

The BER versus data rate has been measured for three types of conventional SI-POFs of different NAs. The PMU fiber, with the lower NA, is the one showing a better performance at 25m, although this advantage is partially lost for longer lengths. The GH and the HFB, which have the same NA, show a distinct behavior: At 25m the GH is slightly better, while at 50m the best performance corresponds to the HFB. We suggest that this effect can be explained by their different angular diffusion functions that have been estimated for fibers of both types [3, 5]. These diffusion functions determine the power distribution at the first meters of the fiber and thus, underlay the relative differences in modal trajectories and delays, which are behind pulse widening and bandwidth limitations. In fact, the HFB has higher diffusion than the GH, which explains the smaller worsening when changing from 25m to 50m of the HFB, while the GH suffers stronger degradation for the same length change (see Figure 3).

As expected, the OM-GIGA attained higher data rates, but with our set-up it does not reach the range of gigabits because of the limits imposed by the optical transceiver used here. This transceiver has been designed for Fast Ethernet, and its jitter limits its maximum data rate is around 300Mbps, more than enough for its nominal application. This limit is illustrated by the elbow of the BER curves for 5m to 50m in Figure 3. The jitter can be appreciated in the eye diagram of Figure 4 (a) obtained using a short fiber segment. Although there may be more suitable transceivers for the assumed data rates (Gbps) for this fiber, we have intentionally wanted to test our fibers with commercially available equipment. Therefore, we have also measured a 75m long segment of OM-GIGA whose performance is not limited by the transceiver characteristics but by its own attenuation and dispersion jointly. This fact is confirmed by the smoother increase of the BER in the graph for 75m in Figure 3 compared to that for shorter fiber lengths, and by the round eye diagram shown in Figure 4 (b). This increase should occur at higher rates considering the potential capabilities of this fiber, but it seems that, even considering the limits imposed by the transceiver, the fiber bandwidth is below its specifications. In addition, we found that the measured attenuation of this fiber (see Table 1) is higher than the manufacturer nominal attenuation (0.2dB/m) [4]. These discrepancies may be originated by the early stage of production of the measured fiber reel.

We did not find any improvement when displacing the OM-GIGA fiber relative to the emitter or the detector. Spatial filtering has not any effect in a graded-index fiber as the modal dispersion is equalized by its own index variation. For the SI-POFs, however, we found that for a given data rate the BER can be reduced or, for a given BER, the data rate can be increased by displacing the fiber end. The explanation is related to the optical power distribution throughout the fiber, which is determined by its angular diffusion function [3, 5]. In fact, we suggest that the particular shape of this angular diffusion is behind the differences found for the effect of the fiber shift on the emitter.

An improvement is also found at the detector end but the shift range is smaller than at the emitter. Notice that the horizontal scale is half than that for the emitter data. This difference appears because the divergence of the emitter is narrower than the NA of the detector.

To confirm that the origin behind this behavior is inherent to the fiber and to discard spurious reflections at the fiber ends, we made a control experiment: We tested a short segment of the fiber shifting both fiber ends from the emitter and detector following the same procedure that for long fibers but in this case, we did not find a noticeable improvement.

## 5. Conclusions

In this work, we have analyzed the application boundaries of large core PMMA SI and GI POFs, using commercially available transceivers. The GI-POF exhibits the highest data rates, although below its theoretical potential capabilities. We also propose a spatial filtering technique to increase the maximum data rate allowable for SI-POFs by simply shifting the fiber end from the emitter or from the detector. These improvements can be also achieved by using sources adapted to the fiber or detectors with a smaller area. However, the spatial filtering has not a noticeable effect over the GI-POF.

## 6. Acknowledgements

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## 7. References

[1] J. Faller, "POF for structured Cabling in Homes and Small Business," Tutorial of the POF World West, (Santa Clara, USA 2006).

[2] B. Offenbeck, S. Junger, W. Tschekalinskij, N. Weber, "Possibilities and limitations of data communications over large core diameter PMMA POF," in Proceedings of the 15th International Conference on Polymer Optical Fiber (ICIPOF, Seoul, 2006), pp. 82-87.

[3] M.A. Losada, J. Mateo, L. Serena, "Analysis of propagation properties of step-index plastic optical fibers at non-stationary conditions," in Proceedings of the 16th International Conference on Polymer Optical Fiber (ICPOF, Torino, 2007).

[4] C.H. Park, K.S. Yoon, J.K. Lee, O. Kwon, "PMMA-based GI-POF and its application to optical interconnects," in Proceedings of the 15th International Conference on Polymer Optical Fiber (ICPOF, Seoul, 2006), pp. 292-296.

[5] J. Mateo, M.A. Losada, I. Garcés, J. Zubia, "Global characterization of optical power propagation in step-index plastic optical fibers," Optics Express 14, 9028-9035 (2006).