Comparative Analysis of the Transmission Capabilities of Large Core Plastic Optical Fibres

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ABSTRACT
In this work we characterize the transmission capabilities of several one millimetre diameter plastic optical fibres (POFs) by analyzing their behaviour at a wavelength in the visible range using a bit error rate (BER) measurement system that allows data rate sweeping. We focus our investigation on transmission data rates in the gigabit range and in-home application distances. The data rate limit for each fibre length extracted from our measurements shows that large core plastic optical fibres are suitable candidates for home and office networks. Moreover, conventional step-index plastic optical fibres (SI-POFs) exhibit error free transmission of Gigabit Ethernet (GbE) data over 25 m, which is a reasonable length for in-home applications. However, only the tested graded-index plastic optical fibre (GI-POF) has been able to transmit GbE data at a 50-m length, which could be extended with a lower attenuation fibre.
Keywords: Plastic Optical Fibre, POF characterization, in-home networks.

1. INTRODUCTION

Plastic optical fibre (POF) has emerged as a low-cost alternative to traditional copper cabling in office or in-home applications [1]. Large core polymethylmethacrylate step-index plastic optical fibres (PMMA SI-POFs) are lightweight, robust, cheap and easy to install. Additionally, the use of 650-nm red light improves the safety for the user and installer's eyes. These mechanical and optical characteristics are derived from the large fibre core and high numerical aperture (NA) of these fibres. These advantages, however, are coupled with two important drawbacks: high attenuation and strong multimodality. The latter characteristics have so far limited the use of SI-POFs to short reach and low bit rate applications. New graded-index plastic optical fibres (GI-POFs) have made it possible to increase transmission distance at high data rates which is suitable for applications such as Gigabit Ethernet (GbE) and digital video interface. However, small core GI-POFs partially lose the traditional advantages of the large core POFs. On the other hand, 1mm-core-diameter PMMA GI-POFs represent a trade-off between the advantages of graded-index and large core POFs.

The main goal of this paper is to assess the overall behaviour of large core PMMA GI-POFs and to compare it with that of conventional SI-POFs by measuring the Bit Error Rate (BER) at different data rates [2]. For this purpose, we have tested fibres from different manufacturers. The data rates analyzed were in the range from 600 Mb/s to 2.2 Gb/s, and the fibre lengths were 25 and 50 m. An analysis of our results permits to determine the application scope for each fibre type.

The paper is organized as follows: In the first section, we present the experimental setup used for the measurements, which includes a description of the tested fibres and the optoelectronic components. The following section shows our experimental results for the different fibres and lengths. In the discussion, we analyze our results to assess the propagation properties of the tested fibres. In the last section, we summarize the conclusions derived from the obtained results.

2. EXPERIMENTAL SETUP

Figure 1 shows the schematic of the experimental setup used in our measurements. The main module is the transceiver (FOT-FOR), which has been designed to work optimally for GbE (data rate of 1.25 Gb/s). It is based on the commercially available EDL1000G-510 transceiver from Firecomms, which is composed of a Vertical Cavity Surface Emitting Laser (VCSEL) operating at 665 nm and a receiver specifically designed for POF applications. The interface to the fibres is performed by the OptoLock™ connector. The BER measurement system is based on the OptoBERT OPB3200 from Optellent, which incorporates a PRBS generator that supports continuously variable data rates from 100 to 3150 Mb/s. The optical signal is obtained by feeding the PRBS to the optical transmitter and is propagated through the fibre, while at the fibre end the receiver circuit regenerates the signal which is injected to the BER tester (BERT). Specifically designed software allows us to measure the BER as a function of data rate by performing a custom scanning of the bit rate.

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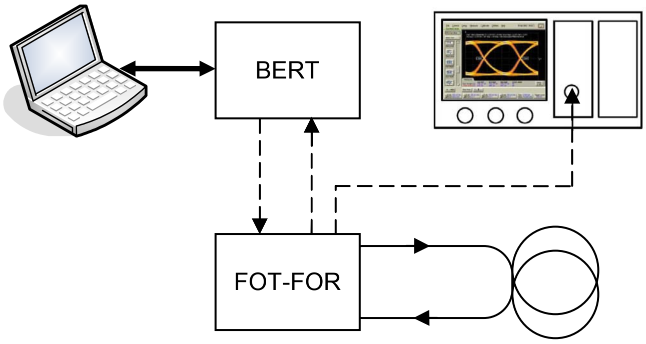


Figure 1. Experimental setup for the comparative analysis of POFs.

In the comparative analysis we have used several 1mm-core-diameter PMMA POFs with SI profiles from different manufacturers: a broadband fibre the PMU-CD1002-22-E (PMU) from Toray with relatively low NA of 0.33, the HFBR-RUS500 fibre (HFB) from Hewlett-Packard with NA of 0.47 and the ESKA PREMIER GH4001 (GH) from Mitsubishi with NA of 0.5. Finally, to compare these fibres with large core GI-POFs, we have tested the OM-GIGA, from Optimedia [3], which also has 1mm-diameter core.

For the measurements, we considered a 2^7 -1 pattern length PRBS at the transmission side of the POF link, which is adequate to emulate Ethernet 8B/10B encoding. Thus, we can evaluate the transmission characteristics of different POFs in GbE links by obtaining BER and eye diagrams directly using a computer controlled system. The experimental procedure was the following: we started with a 50-m length and did a coarse scanning of the data rate to establish the point at which the errors arose. Then, from this obtained minimum, we performed a finer scan in 1-Mb/s steps up to the rate where the BER reached 10^{-2}. The BER was obtained by accumulating the errors over a gating time window whose value was set to 1 minute. Then, this procedure was followed for the same fibre with a 25-m length.

3. RESULTS

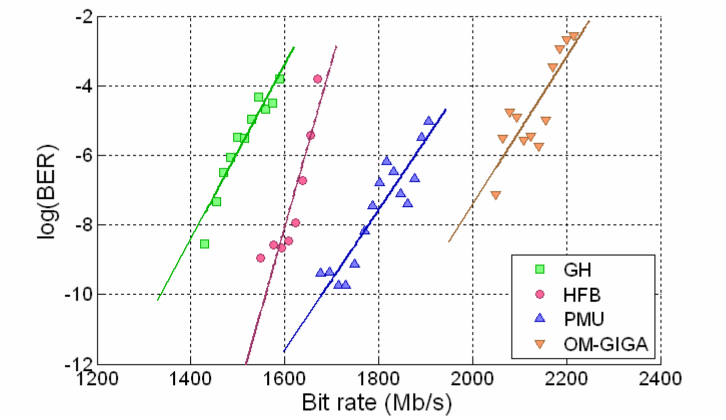
First the attenuation factor of the tested fibres was obtained from the received optical power measured with a standard power meter for lengths of 25 and 50 m. To resemble final-user situations, the detected power was intentionally measured under imbalanced modal conditions using the same emitter employed in our setup. For this reason, the obtained attenuation is different for each length as show the values in Table 1. In addition, the receiver sensitivity was measured for a BER of 10^{-9} and a bit rate of 1.25 Gb/s. The obtained sensitivity was -19.2 dBm, which guarantees enough power budget even in the worst case as can be seen in Table 1.

Table 1. Detected power and measured attenuation for the tested fibres.

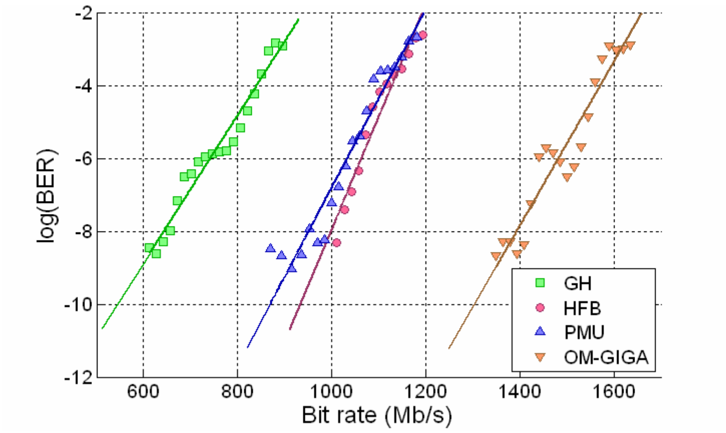
Fibre	Length = 25 m		Length = 50 m	
	Detected power	Attenuation	Detected power	Attenuation
GH	-11.2 dBm	0.24 dB/m	-14.8 dBm	0.19 dB/m
HFB	-12.4 dBm	0.16 dB/m	-14.1 dBm	0.15 dB/m
PMU	-11.9 dBm	0.23 dB/m	-16.9 dBm	0.21 dB/m
OM-GIGA	-11.9 dBm	0.22 dB/m	-18.1 dBm	0.23 dB/m

We have plotted the measured BER versus data rate in Mb/s for the four fibres considered. These results are shown for a 25-m fibre length in Figure 2(a) and for 50-m fibre length in Figure 2(b). In these plots, the vertical axis shows the decimal log of the BER while the horizontal axis represents the data rate in Mb/s.

As expected, the BER exhibits an approximately linearly increasing tendency with data rate, being both steepness and bit-rate offset dependent on the fibre type and length considered. More particularly, taking into account the bit rates for which BER = 10^{-6} was measured, it is possible to compare the performance of the fibres and assess their applicability. Table 2 shows the values of bit rate for all fibres and lengths.



(a)



(b)

Figure 2.Transmission performance of the tested fibres as a function of the bit rate for (a) 25-m and (b) 50-m lengths.

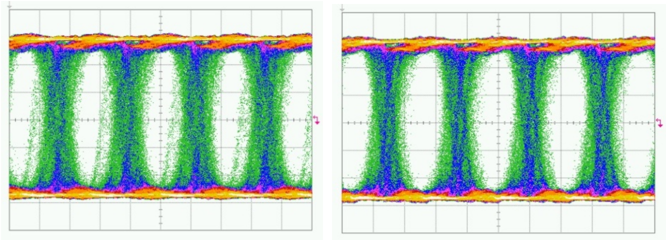
Table 2. Bit-rate values for which BER=10^{-6} was measured.

Fibre	Length = 25 m	Length = 50 m
GH	1496 Mb/s	742 Mb/s
HFB	1644 Mb/s	1063 Mb/s
PMU	1878 Mb/s	1033 Mb/s
OM-GIGA	2067 Mb/s	1482 Mb/s

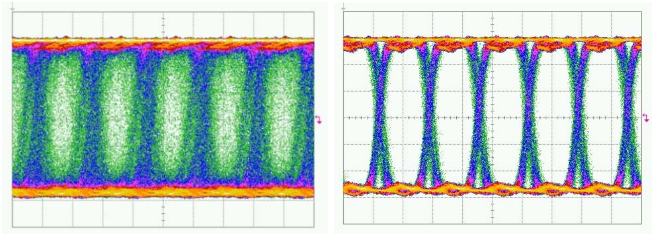
4. DISCUSSION

Our attenuation measurements proved that power is not a limiting factor for the studied fibre lengths and thus, we will focus our discussion on the BER dependence on the bit rate. For fibre lengths of 25 m, the lower NA PMU fibre is the SI-POF showing a better performance followed by the HFB and the GH. As expected, the OM-GIGA has the best behaviour reaching more than 2 Gb/s at 10^{-6} BER. These results show that all the tested fibres are suitable for GbE applications for distances up to 25 m.

One of the effects of increasing fibre length is that the BER sensitivity to changes in rate is reduced and thus, the performance of all the fibres has more similar slope. Additionally, for fibre lengths of 50 m, some fibre roles have changed. In this case, the HFB has a better behaviour than the PMU, while the GH and the OM-GIGA keep their relative performances. This effect is illustrated by the eye diagrams in Figure 3. Figure 3(a) shows the eye for the PMU with a BER in the range of 10^{-7} at 1 Gb/s, and Figure 3(b) for the HFB with a BER in the range of 10^{-8} and the same data rate. Figure 3(c) shows the eye diagram for the PMU for GbE which is similar to the eye at the same rate for the HFB. For both fibres at this data rate the BER is above 10^{-2}. Therefore, the tested SI-POFs are not suitable for GbE for a distance of 50 m.



(a) PMU at 1 Gb/s data rate *(b) HFB at 1 Gb/s data rate*



(c) PMU at 1.25 Gb/s *(d) OM-GIGA at 1.25 Gb/s*

Figure 3.Eye diagrams for 50 m of three fibre types.

The capabilities of the OM-GIGA have been confirmed by measuring the eye diagram for 50 m at GbE data rate which is shown in Figure 3(d). This eye diagram is completely open, indicating the error-free performance for 50 m of this fibre type at GbE, which is consistent with the previous BER measurements. However, our results show that the maximum length for this fibre at GbE is not much higher than 50 m, being the factor limiting maximum length the fibre attenuation. In fact, our measurements in Table 1 show that the attenuation for the OM-GIGA is higher than that specified by the manufacturer (0.2 dB/m) [3].

Transmission performance degradation with bit rate is due to modal dispersion, but the fibre differential behaviour with length can be explained by their different diffusion characteristics. Particularly, in previous works [4, 5] we found that the HFB has very strong mode mixing which explains why for 50 m its performance degrades less than that for the other fibres. Also, we suggest that the improvement in the linear tendency and the increased homogeneity of the slopes for 50 m can be explained by the differential mode attenuation. This effect reduces power from the outer modes which have a higher variability in their transit time.

5. CONCLUSIONS

In this work, we have demonstrated the technical feasibility of the use of large core POFs for home applications. BER versus data rate has been measured for three types of conventional SI-POFs of different NAs and for one large core GI-POF. The presented results show error free transmission of GbE for all tested POFs over 25 m, which is a suitable distance for in-home applications.

For 50-m length, none of the SI-POFs are applicable to GbE data transmission, but the PMU and HFB fibres with relatively low NA (0.33 and 0.47, respectively) can be used for data rates up to 1 Gb/s. The GI-POF exhibits the best transmission capabilities, allowing transmission of GbE over 50 m. In this case transmission performance is power-limited rather than bandwidth-limited, although this issue could be overcome by increasing the power budget. The obtained results are very interesting nowadays due to its application in short reach links inside the home, such as for example high-definition digital TV connections.

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