High-Speed (11 Gbit/s) Data Transmission Using Perfluorinated Graded-Index Polymer Optical Fibers for Short Interconnects (<100 m)

Giorgio Giaretta, Whitney White, Mark Wegmuller, and Tsuyoshi Onishi

***Abstract*—Perfluorinated graded-index polymer optical fibers (GI-POF's) have been developed that offer low losses (<50 dB/km) and high bandwidth (>0.3 GHz·km) at data communication wavelengths (0.85 and 1.3 μm). Here we demonstrate that such fibers can support data rates up to 11 Gbit/s for 100 m with low-power penalty and large-power margins. Although a restricted launch was used, differential mode delay measurements show that, in a large central region of the fiber core (50% of the core diameter), very large bandwidths can be obtained with modest alignment requirements. These improved transmission characteristics (obtained using inexpensive, uncooled, unisolated 1.3-μm Fabry–Perot sources and pin detectors) together with potential low-cost connectorization and a small fiber bend-radius make perfluorinated GI-POF's a candidate for premise networks and short-reach telecom and computer interconnections.**

***Index Terms*—Optical communications, polymer optical fibers.**

I. Introduction

THE DEMAND for bandwidth in the premises is rapidly increasing, fueled by video- and graphic-rich applications. However, a cost-effective and future-proof means for bringing high bandwidth services to the individual users on a mass basis has not yet emerged. Several competing technologies are under consideration: unshielded twisted pair (UTP) copper wire, coaxial cable, wireless links, single and multi-mode glass optical fibers (GOF's), and plastic optical fibers (POF's).

Although glass fiber solutions have the potential of achieving very large bandwidths, they suffer from high connectorization costs compared to copper or wireless solutions. For this reason, glass fiber has not been widely adopted by the end user (premises) where most of the interconnections are needed and less cost-sharing between users is obtainable. Large core POF's have been introduced to solve this problem [1]. Although polymethiylmethalacrylate (PMMA) POF fibers have been demonstrated to obtain very high transmission bandwidth [2], they suffer from high losses (150 dB/km) and operate at 650 nm outside of the communication wavelengths where high-speed transceivers are more mature and achieve higher performances.

Recently, a new type of POF, the perfluorinated plastic optical fiber (PF-POF), has been introduced that has low losses and high bandwidth at communication wavelengths [3]–[5]. Previous works have shown that losses as low as 50 dB/km are achievable at 1.3-μm wavelengths [4] and have demonstrated bandwidths as high as 0.3 GHz/km [5], [6].

In this letter, we demonstrate for the first time that data transmission at rates as high as 11 Gbit/s can be achieved over 100 m of perfluorinated GI-POF with inexpensive, 1.3-μm, uncooled, unisolated, Fabry–Perot (FP) laser sources and a low-cost pin receiver. The link achieved error rates of 10^{-10} with a link power budget of less than 9 dB operating within the eye-safety Class 1 standard.

Differential mode delay results show that one would expect very large bandwidths to be achievable under a wide range of restricted launch conditions as long as very lossy, highly dispersive, high-order mode groups are not excited with very large offset launches.

II. Performance

Fig. 1(a) shows a block diagram of the transmission experiment setup. The laser source used was an inexpensive, uncooled, unisolated, pigtailed FP laser, modulated with a nonreturn-to-zero (NRZ) $2^{15}-1$ pseudorandom bit sequence (PRBS) at 11 Gbit/s. The launched power in the perfluorinated GI-POF was only 0 dBm (Class 1 eye safety compliant source). The coupling from the single-mode pigtail to the plastic optical fiber was obtained using a collimating and focusing lens pair. It is important to notice that there is no need for the SM fiber and a more practical system would have the source directly coupled to the plastic fiber, as shown in Fig. 1(b). The perfluorinated plastic optical fiber (the core diameter was 130 μm with a 300-μm cladding diameter) had a low loss of only 33 dB/km. The receiver was composed from a fiber-coupled (62.5 μm MMF) high-speed 50-Ω-terminated pin detector and a chain of electrical amplifiers. The bandwidth of the receiver was limited from the frequency response of the amplifiers to 10 GHz. A collimating and a focusing lens was used to minimize the coupling losses between the GI-POF and the GOF due to the mismatch of the numerical apertures and the core diameters. A coupling loss of 4.8 dB was measured. Fig. 1(b) shows a more practical low-cost receiver that would eliminate the 4.8-dB coupling loss using a 2–3 times demagnifying lens system.

Using the setup of Fig. 1(a), we have achieved error rates of 10^{-10} after transmission trough 100 m of perfluorinated GI-POF [see Fig. 2(a)]. It is important to notice that the received power is -8.6 dBm with less than 9 dB of link power budget.

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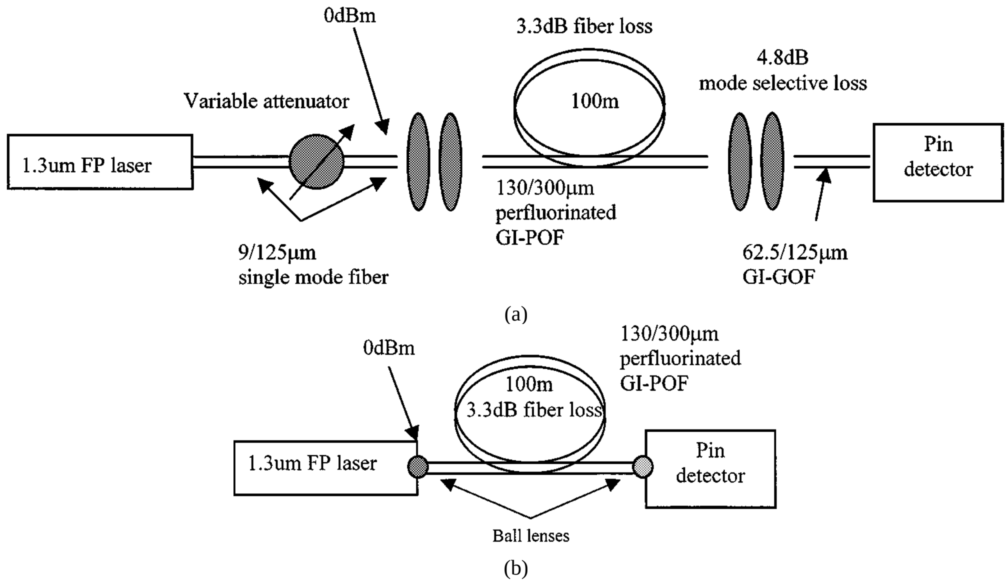


Fig. 1. (a) Experimental setup for the transmission experiment using an inexpensive, uncooled, unisolated, pigtailed FP laser source at 1.3 μm and a pin detector. (b) A more practical improved system that could be fabricated with components packaged for POF applications. Here both the source and the detector are directly coupled to the POF through a ball lens decreasing the high coupling losses and the large modal noise present in the current implementation, which uses commercially available single-mode and multimode high-speed components.

This implies that an eye safety Class 1 compliant transmitter at 1.3 μm (<+8 dBm optical power) will allow the fabrication of a link with a power margin of at least 7 dB. On the other hand, a real system would include at least 2–4 connectors with an equivalent connection loss of about 2–4 dB.

The bit-error-rate (BER) measurements in Fig. 2(a) show a power penalty of 2.5 dB for the link at error rates of 10^{-10}. We believe that a large portion of this penalty is due to the modal noise generated from the highly mode-selective loss introduced from the POF-GOF connection, which can be eliminated through proper direct coupling of the POF to the detector. Fig. 2(b) shows an open eye diagram at -8.6 dBm of received power.

In order to understand the influence of launch conditions on the fiber bandwidth, we have performed several differential mode delay (DMD) measurements [7] on the 100-m perfluorinated GI-POF. Fig. 3(a) shows in a compact way such measurements. Each vertical slice of the plot shows the impulse response of the fiber for a given offset launch (horizontal axis). The intensity of the impulse response is color coded as a function of time (vertical scale). Very high bandwidths (1–2 GHz·km) are clearly achievable in an 80-μm central region of the fiber core and are, to first order, independent of the launch position. Fig. 3(b) shows the same data plotted in a more conventional way (overlapped impulse responses) for a few offset positions.

The reason for such high bandwidths over a very large region (50%) of the fiber core is believed to be the very large mode mixing among mode groups, as reported in [8]. A detailed examination of mode coupling is presented in [9]. Large mode mixing is responsible not only for the relative insensitivity of the fiber bandwidth to the graded index profile [10] but also for the insensitivity of the fiber bandwidth to the launch conditions. As we have demonstrated, this large flat region in the DMD mea-

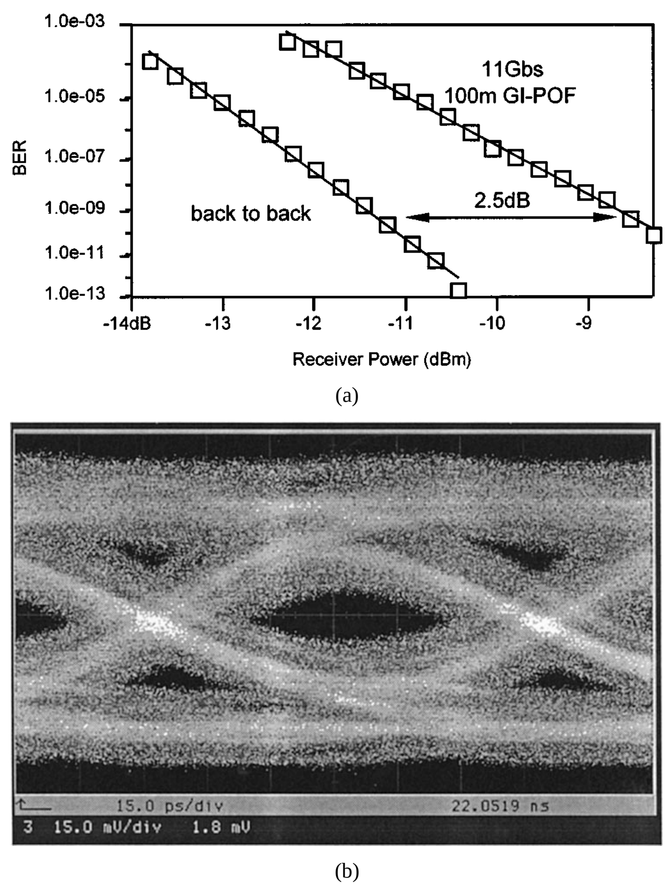
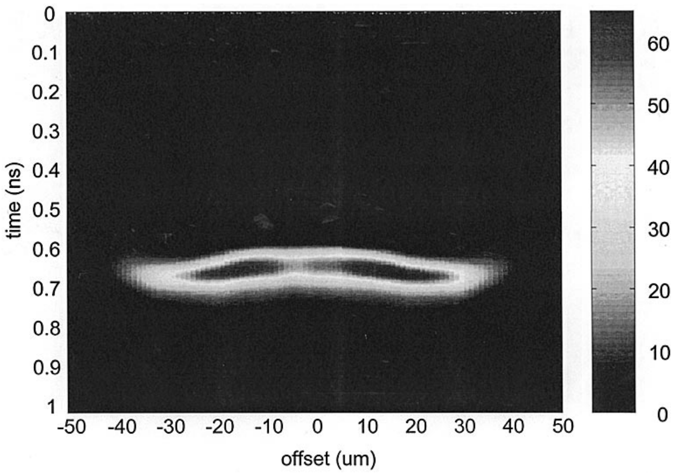
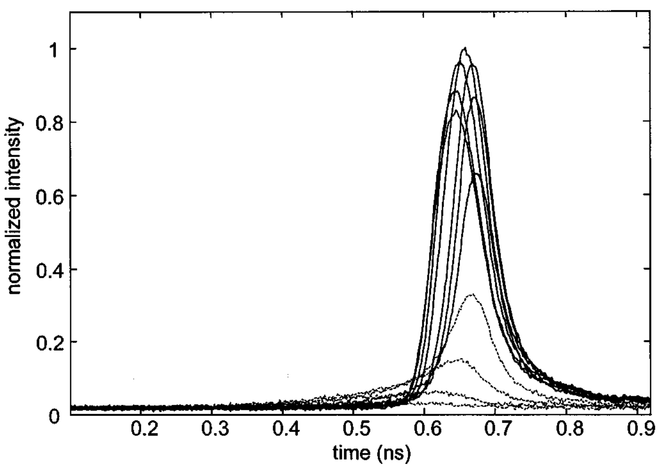


Fig. 2. Transmission experiment results. (a) BER measurements back to back and through the 100-m GI-POF. The measurements show error rates of less than 10^{-10} at -8.6 dBm. The power penalty of 2.5 dBm is attributed to modal noise generated from the 4.8-dB mode-selective loss induced from the coupling of the GI-POF to the GI-GOF. The back-to-back measurement was performed using a single-mode fiber coupling from the laser to the detector. (b) Open eye diagram at 11 Gbit/s at -8.6-dBm receiver power.



(a)



(b)

Fig. 3. Differential mode delay of 100 m of perfluorinated GI—POF at 1.3 μm. (a) Fiber impulse response as a function of offset restricted launch. Very uniform and narrow pulses are measured, indicating a very high restricted bandwidth in 50% of the fiber core. (b) Overlapped fiber impulse responses for a few of the offset positions in (a). High restricted bandwidth ($>$8 GHz) is obtained in the inner 50% of the fiber core radius (solid curves).

surements can be easily exploited to transmit very high bit rates with modest alignment requirements.

III. Conclusions

In this letter, we have demonstrated for the first time that perfluorinated graded-index plastic fiber can support transmission up to 11 Gbit/s for 100 m with low losses at communication wavelengths, within eye safety standards and with large power margins. These results have been achieved using low-cost FP laser sources at 1.3 μm and inexpensive pin detectors, making perfluorinated POF a promising candidate for high-speed premises interconnects and short-reach telecom and computer interconnections. We have also shown that large fiber bandwidths are achievable using restricted launches that are insensitive to the launch position and therefore can be achieved without requiring accurate mechanical alignment.

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