Gigabit Ethernet Transmission Experiments using GI-POF

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Gigabit Ethernet transmission experiments using perfluorinated Graded Index-Polymer Optical Fiber (GI-POF) over record distances in the order of 1 km and at wavelengths in the 850 and 1300 nm area are reported. The bit rate of the experiments is 1.25 Gbit/s, taking into account the 8B10B block coding commonly used in the Gigabit Ethernet physical layer. The Gigabit Ethernet standard supports a maximum length of 100 m over copper wire, 550 m over multi-mode glass optical fiber, and 5 km over single-mode fiber. These 1 km experiments show that GI-POF, which is easy and cheap to install, is a very strong candidate for short to medium distance Gigabit Ethernet applications.

Introduction

The Ethernet protocol is used on 80 to 85 percent of the world's LAN-connected PCs and workstations because it has been adapted to meet the changing needs of its customers while remaining simplicity, interoperability, robustness, and low cost [1]. The first generation Ethernet was defined in 1985 and worked at a data rate of 10 Mbit/s. Fast Ethernet, which became a standard in 1995, uses the same Ethernet frame format but with ten times the transmission speed namely 100 Mbit/s. Gigabit Ethernet is the most important recent addition to the Ethernet protocol, which is capable of transmission of 1,000 Mbit/s, so again ten times faster. The Gigabit Ethernet physical layer uses 8B10B block coding to add extra data clock information, to reduce the low frequency components, and for error detection. In this coding technique, 8 bits of data are encoded to 10 bits, increasing the link transmission rate to 1,250 Mbit/s.

System experiments

In Fig. 1 a block diagram of a Gigabit Ethernet transmission experiment is shown over a distance of 990 m and at a wavelength of 840 nm. Key elements used in this experiment are an improved low-loss GI-POF launched with only a few modes, a Vertical Cavity Surface Emitting Laser (VCSEL) with a small spectral width and a high bandwidth of 2 GHz, and a silicon Avalanche Photodiode (APD) with a large active area of 230 micron in diameter. The total link of 990 m was built by cascading 3 separate samples of 330 m each. The Bit Error Rate (BER) as a function of received average optical power at the input of the APD has been measured, Back-to-Back and after 990 m GI-POF transmission; see Fig. 2. The Back-to-Back measurement has been carried out with a short piece of fiber of a few meters between transmitter and receiver. The received power has been changed by altering the distance between laser and GI-POF.

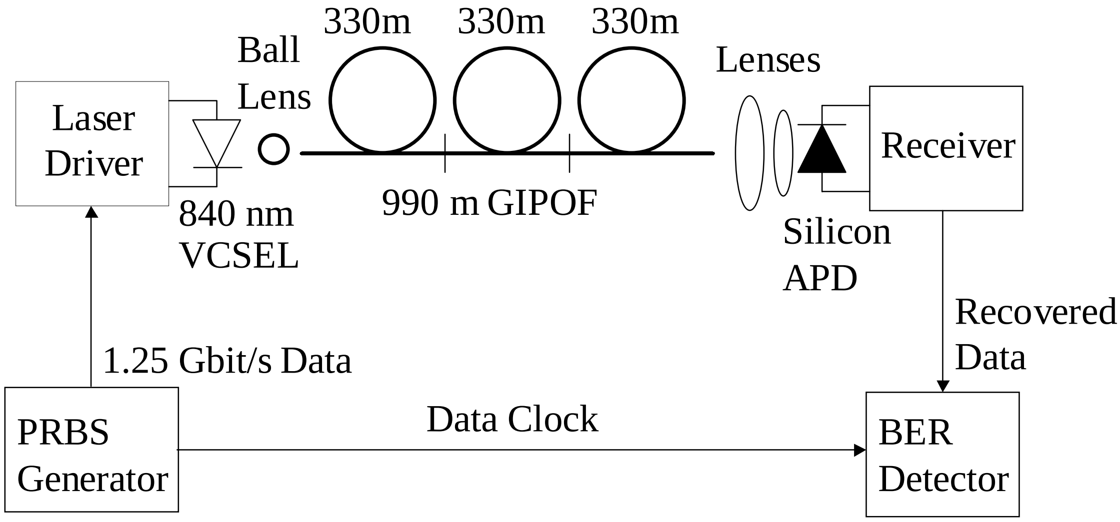

Figure 1: Set up of the Gigabit Ethernet transmission experiment at 840 nm.

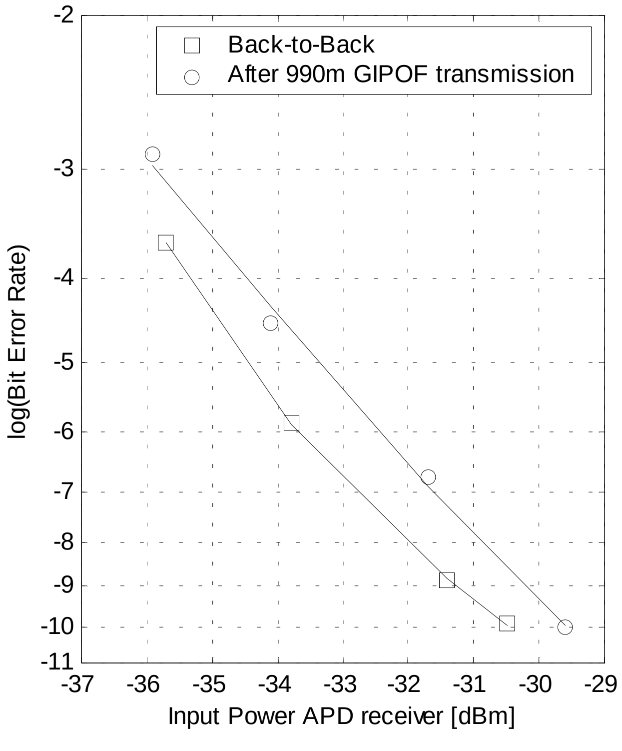

Figure 2: Bit Error Rate measurement results 840 nm experiment.

The measurements were carried out using a Non Return to Zero (NRZ) Pseudo Random Binary Bit Sequence (PRBS) with a pattern length of 2^{23}-1.The average output power of the VCSEL was 1.1 dBm, and the sensitivity of the receiver was –31.3 dBm for a BER of 10^{-9}, and at a bit rate of 1.25 Gbit/s, see Fig. 2, so the available power budget was 32.4 dB.

The total attenuation of the 990 m GI-POF link at 840 nm wavelength was 26.9 dB, so the average attenuation of this fiber is about 27 dB/km at 840 nm wavelength. In a previous reported GI-POF transmission experiment a distance of 550 m was reached using a fiber with an attenuation of 43.6 dB/km at 840 nm wavelength [5]. The bit rate in this experiment was 2.5 Gbit/s. A 1.1 dB receiver sensitivity degradation was observed at a BER of 10^{-9}, see Fig. 2, due to multi-mode dispersion of the fiber and due to modal noise. The optical signal of the VCSEL is coupled into the GI-POF using a ball lens and at the receiving end lenses are used to couple the light out of the GI-POF on the APD. The total coupling loss from VCSEL to GI-POF and from GI-POF to APD was 2.6 dB, so a total power budget of 30.6 dB was needed. This results in a system margin of 1.8 dB.

The modulated spectral width of the optical output signal of the VCSEL was smaller than 1 nm. This small value certainly diminishes the impact of the material dispersion of the fiber. The dispersion is further reduced by tailoring the launching condition of the optical signal at the fiber input. Only a few modes are excited because the core of the GI-POF is only illuminated by a small spot. Thus the number of propagating modes is less than at fully launched condition, implying less modal dispersion and thus a further bandwidth improvement [6].

In Fig. 3 the set up of a Gigabit Ethernet GI-POF transmission experiment is shown using a commercially available Gigabit Ethernet transceiver in combination with a matching evaluation board. With this system a distance of 330 m has been bridged with a BER smaller than 10^{-11}. The wavelength of the VCSEL of the transceiver was 850 nm and the output power was –9.3 dBm. The sensitivity of the PIN photodiode receiver was –20.0 dBm for a BER of 10^{-9}, so the available power budget was 10.7 dB.

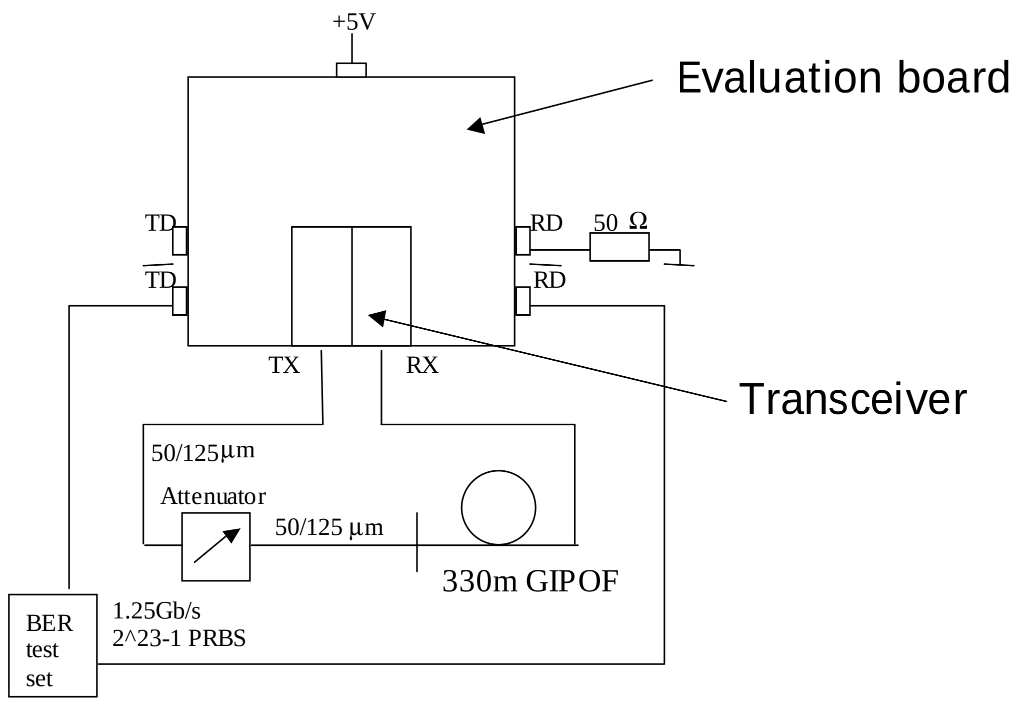

Figure 3: Set up of the transmission experiment using a commercially available Gigabit Ethernet transceiver.

Moreover, a Gigabit Ethernet transmission experiment over a distance of 660 m at a wavelength of 1310 nm has been carried out. Key elements used in this experiment are a low-loss GI-POF, a Distributed Feed Back (DFB) laser with a bandwidth of 5 GHz, and a InGaAs APD with a large active area of 80 micron in diameter. The used laser was provided with a single mode silica fiber pigtail that was butt coupled with the GI-POF, launching only a few modes. The attenuation of the 660 m GI-POF at 1310 nm was 20.3 dB, the output power of the laser 1.1 dBm and the sensitivity of the receiver –27.9 dBm. The attenuation of 990 m GI-POF at 1310 nm is 34.0 dB so the available power budget of 29.0 dB is not enough. By using a Semiconductor Optical Amplifier (SOA) between the DFB laser and the GI-POF, the power at the transmitter site has been increased to 10 dBm. However, the noise introduced by the SOA decreased the receiver sensitivity with 4.3 dB. A BER of $1.3*10^{-4}$ has been reached with this 990 m Gigabit Ethernet experiment at 1310 nm. The attenuation of the GI-POF is about 5 dB lower at 1290 nm compared with the attenuation at 1310 nm. Probably, a BER of less than 10^{-9} can be obtained at this shorter wavelength.

Conclusions

GI-POF 1.25 Gbit/s transmission experiments in the 850 and 1300 nm wavelength area have been reported, achieving maximum distances of nearly 1 km, showing the applicability of these fibers for Gigabit Ethernet applications in customer premises and local area networks. We believe that these record results are an important milestone that may further encourage the development of polymer fiber systems.

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