10 Mbit/s LAN using 650 nm LED and Step-Index Polymer Optical Fiber up to 100 m

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Summary

In this paper we report on the performance of a 1 mm diameter Step-Index POF-LAN designed for low cost and high volume applications. A 10 Mbit/s Ethernet test system consisting of an active star coupler and transceivers supports link lengths of 100 m and link budgets up to 27 dB with 650 nm light-emitting diodes. All components of the system are commercially available. To test the efficiency in a realistic environment the system has been incorporated in the campus-wide LAN of the University of Ulm. Long-term investigations show reliable data transmission to a BER less than 10^{-9}.

Introduction

The 10 Mbit/s Ethernet standard is by far the most commonly used Local Area Network (LAN) standard. It is and will be applied for years to come in a wide range of applications. Today and in the near future, Electromagnetic Compatibility (EMC) requirements play an increasing role for equipment systems. The use of polymer optical fibers as the optical fiber link attachment technology offers at lowest cost the potential for a totally Electromagnetic Interference (EMI) free, interconnect environment and reduces peripheral equipment sizes. However in order to obtain wide acceptance for fiber to desk applications, it is necessary to use a low total system cost suitable for transmission distances up to 100 m. Instead of only relying on tests under laboratory conditions, we installed an LED-based Ethernet-LAN with Step-Index POF in a realistic environment. The POF-LAN was incorporated into the working LAN at the University of Ulm. This paper describes the design and performance features and reports on the operation and reliability of the system.

Experimental Set-Up

The POF cabling installation consists of 73 offices on 6 floors with interconnecting distances of 30 m to 100 m. The POF were installed without special handling. In order to manage the number of connections in the distributor room a patch panel was used. The cables lead to the wall outlets in the offices. With this set-up, an entire link from an active modular hub system to a workstation or personal computer requires at least two additional connections, one at the patch panel and the other at the wall outlet. To obtain first results, four workstations were provided with AUI-Interface POF transceivers and linked to the terminal POF-transceivers of the star coupler. The POF hub was integrated into the network and monitored by simple network management protocol (SNMP). Each link consists of 15 significant bends, 9 with a radius of 30 cm, 4 with a 10 cm radius and two of them have the smallest radius of 3 cm.

Plastic Optical Fibers

The fiber we used is a commercially available EP 51 Duplex step-index fiber (Hoechst AG[1]). It consists of a 0.97 mm Polymethylmethacrylate (PMMA) core with a 0.015 mm Fluoropolymer cladding. The two 2.2 mm diameter Polyethylene (PE) jackets are molded together to form a duplex cable. The optical properties are specified for an attenuation less than 190 dB/ km at 650 nm, a Numerical Aperture of 0.46 and a transmission bandwidth of 90 MHz × 100 m.

Connectors

On the patch panel and the wall outlets FSMA plugs with crimp eyelet as strength member were used. For easy handling the fiber ends of the FSMA-plugs were end finished by the hot-plate-method without polishing. The terminal components were linked by plastic Versatile fiber connections of Hewlett Packard. The connectors were crimped to the fiber jacket and the fiber ends were finished with grinding and polishing.

Terminal Components

Due to the steep increase in attenuation on both edges of the POF´s narrow transmission window around 650 nm, it is necessary to use powerful visible LEDs with a center wavelength close to 650 nm. To match the optical coupling properties of the POF, specially selected POF receivers have to be used at the other end. For this purpose Hirschmann GmbH & Co. modified their commercially available Ethernet systems for silica optical fibers. The 850 nm components of the modular hub Ethernet cards and of the Mini transceivers for the workstations with AUI interface, designated ECFL2 and Mini-OTDE respectively, have been replaced by high power 650 nm LED transmitters HFBR 1527 and PIN/ preamp receivers HFBR 2526 of Hewlett Packard[2].

Results and Discussion

Fiber Length Measurement

To determine the accurate lengths of the installed cables easily we measured the light wave propagation time in a duplex POF cable in short circuit at one end as shown in Figure 1. A Wavetek 166 function generator drives a HBFR 1527 LED with a sinus waveform at a frequency of 380 kHz. The maximum forward current was 125 mA. The signal of the HFBR 2526 receiver was amplified by a 32 dB amplifier with 120 MHz bandwidth. The detected phase shifts between the entrance and exit signals of the POF on a Rohde & Schwarz ZPV vector analyzer had been previously calibrated between 100 m and 200 m to a phase angle of 0.703 degree per meter. The uncertainty in cable length determination of 100 m up to 200 m increase from 0.1 to 0.5 degree/ m respectively, depending on the increasing attenuation of the fibers. The cable lengths determined for the POF-LAN are listed in Table 1.

The phase shift measurements described above were verified by delay time measurements of square wave pulses with a duration of 750 ns and a repetition time of 2600 ns. There is an uncertainty in triggering on the broadened incoming pulse, which causes a lower accuracy of the determination of the fiber lengths. It was not possible to determine the longest cable length with this delay time measurement method because the signal-to-noise ratio was too low. The insertion of a repeater at the far end of the duplex cable would bring in additional delay times and is therefore not practicable.

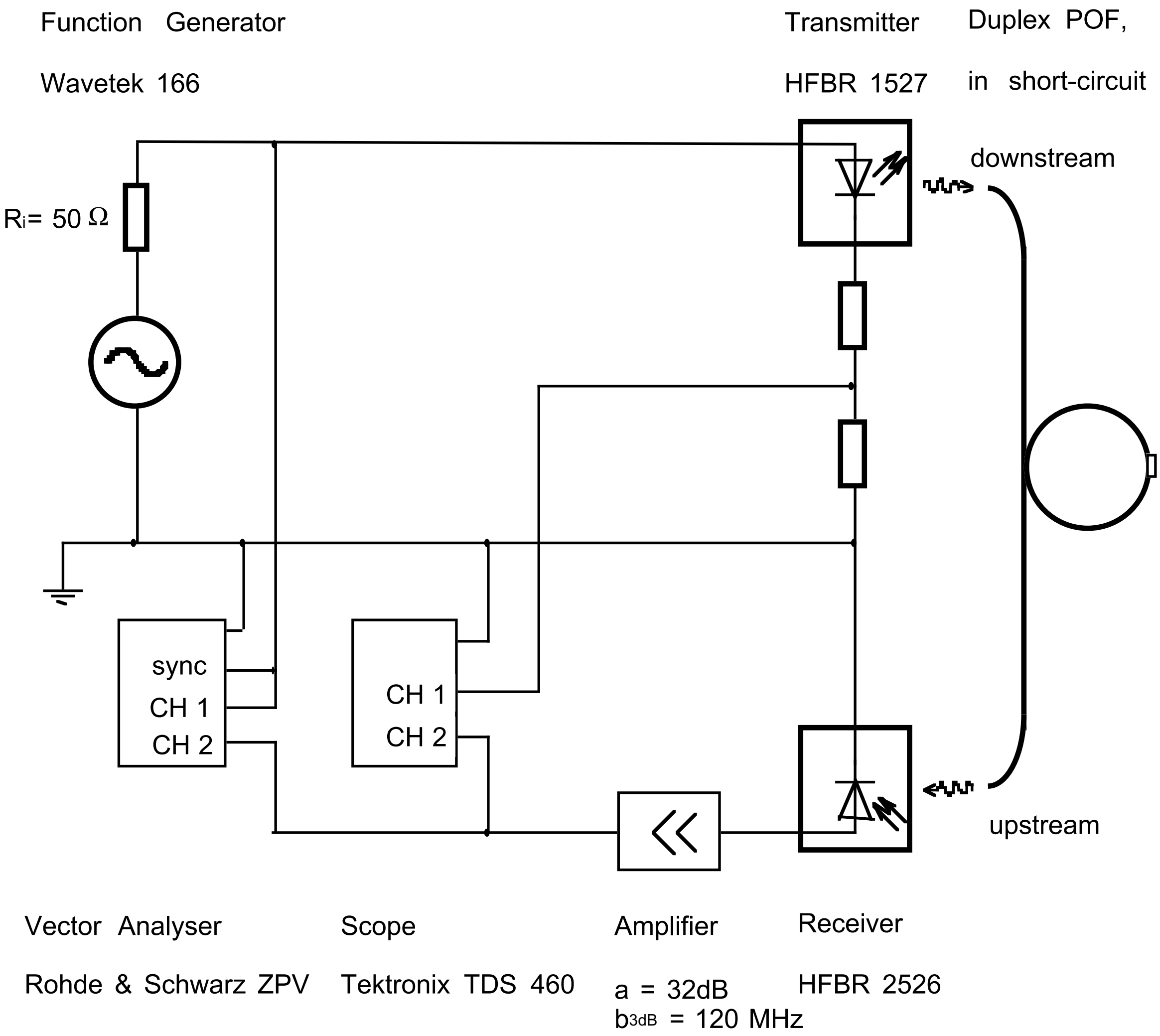


Figure 1: Schematic diagram for fiber length measurement by delay time of light wave propagation, duplex SI-POF is in short circuit by a FSMA-plug at one end.

Attenuation of POF and Connectors

Preparation of the end faces of FSMA-plugs by simply melting the fiber on a hot plate produced a transmission loss of 1.3 dB to 2.3 dB. Additional polishing could lower the attenuation, but the required preparation time does not outweigh the benefit. The HFBR 4501 simple connectors for the terminal components were polished and had losses of 1 dB to 1.5 dB. The total attenuation of the POF cables including the connection losses were measured with a HBFR 1527 LED (652 nm center wavelength) and a HP 8152A optical average power meter and are listed in Table 1.

To understand the remarkably higher attenuation we measured compared to the loss specified by the manufacturer to be less than 19 dB/ 100 m at 650 nm, we have to keep in mind that the spectral attenuation is measured with narrow-linewidth spectrometers while the low-cost POF systems use LEDs. In our case the HFBR 1527 has a spectral width of 27 nm FWHM. Figure 2 shows the POF's spectral attenuation and the spectra of two LEDs with gaussian profiles centered at 650 and 660 nm. It is clear to see that the average loss is higher than the valley's bottom. In the case shown, the attenuation of the 100 m POF at 650 nm is 18.4 dB, with the LED centered at 650 nm the average loss is 21.9 dB and with the other it is 22.6 dB. The center wavelength of 660 nm corresponds with the worst case of an LED working at 70°C.

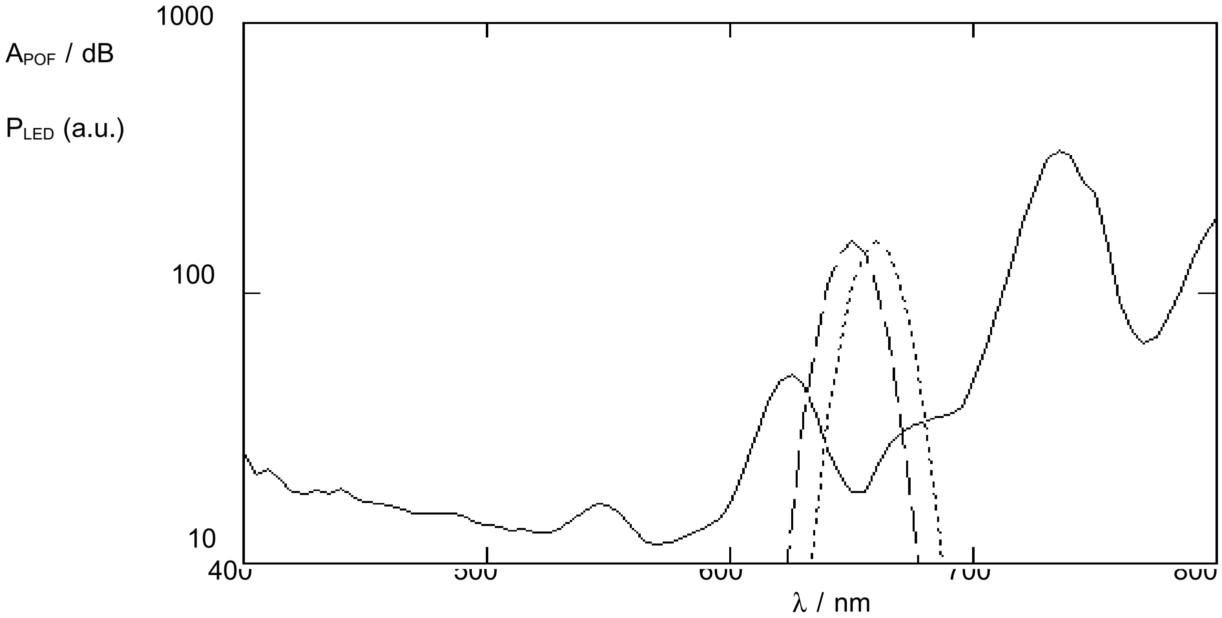
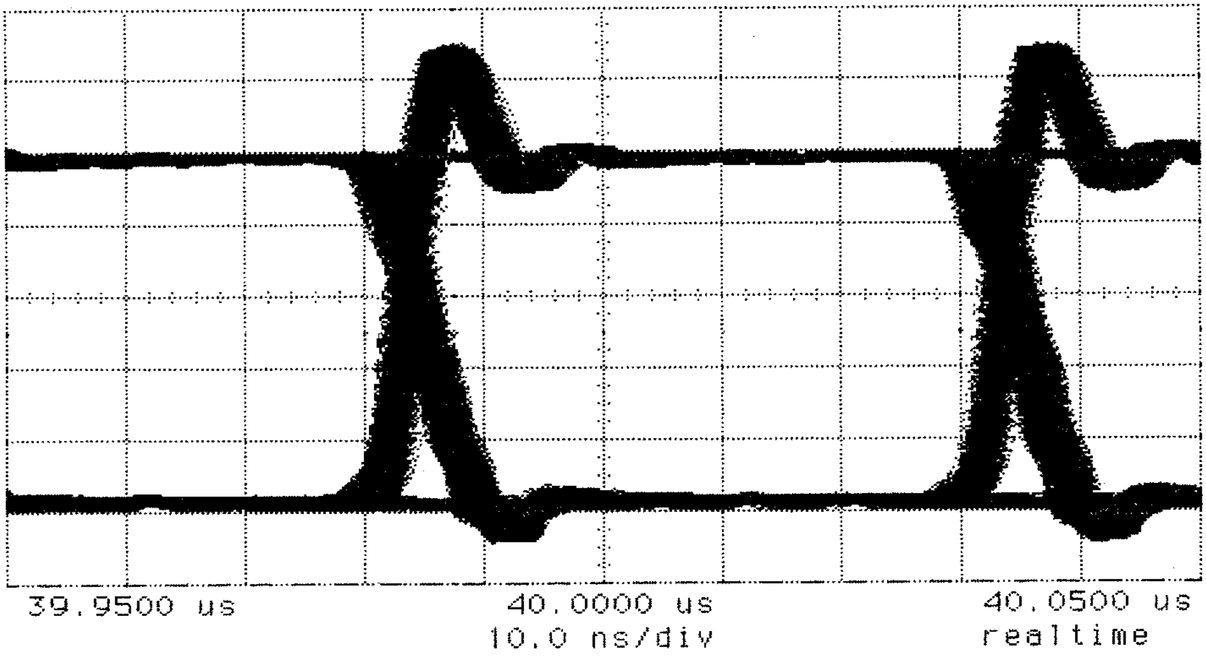


Figure 2: Spectral attenuation of 100 m POF and calculated spectra of two LEDs with gaussian profiles of 27 nm FWHM centered at 650 and 660 nm.

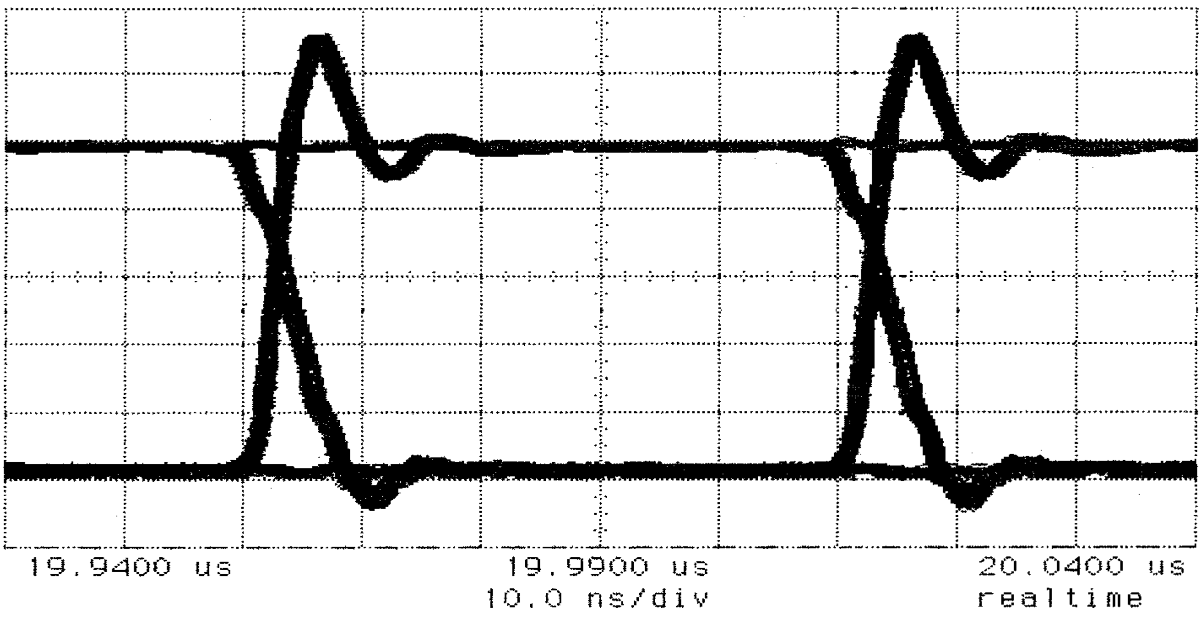
System Performance

The HFBR 1527 transmitter typically launches -3 dBm optical output power into a 1 mm diameter polymer optical fiber with a Numerical Aperture of 0.5. The measured output power of the LEDs after 1 m POF and driven by an average forward input current of 80 mA are shown in Table 1. HFBR 2526 is a high bandwidth analog receiver containing a PIN photodiode and internal transimpedance amplifier with a typical initial optical noise input power of -39 dBm for 1 mm POF. In order to meet EMI and cross-talk requirements the receiver was shielded and the optical input power was limited to a minimum of -31 dBm. With an input power exceeding -2 dBm, signal pulse width distortions occurred at the receiver.

With those POF Ethernet systems the loss budget for an error free data link under worst case conditions ranges between 2.5 and 27 dB. Unpeaked optical rise time from 10 percent to 90 percent is 5.3 ns at a transmission frequency of 10 MHz, while optical fall time is 3.4 ns. Figure 3 shows the eye diagrams after 12 m (6 dB) and after 100 m (25 dB) SI-POF propagation. The LEDs exhibit a slow tail response beyond the fast response region caused by the LED speed-up circuit. This results in a closure of the receiver eye.



b) 100 m, 25 dB transmission



a) 12 m, 6dB transmission

Figure 3: Eye diagrams of 10 Mbit/s data transmission for a) 12 m, 6 dB and b) 100 m, 25 dB SI-POF propagation.

In order to describe the reliability of the POF-LAN we measured the bit error rate (BER) of the opto-electronic components at the beginning of the test and 7 months later. The BER was determined to be less than 10^{-9}. Furthermore, the LEDs optical output power was checked. To keep the system costs low the LEDs have not been burned-in. In most cases this results in a decrease of optical output power with time. Within the accuracy of attenuation measurements the output power of the LEDs in the ECFL2 devices remained unaffected, except the one of room 3. The higher LED power loss in the Mini-OTDE is due to its small housing, which increases the chip temperature of the LED 20 degrees over this of the ECFL2. After burning-in of the LED the output power remained constant.

	Condition	Room 1	Room 2	Room 3	Room 4
Total Attenuation of Duplex Fiber [dB]	up	24.90	21.95	22.73	18.30
	down	24.93	22.76	21.95	18.55
Cable Length [m]		97.6 ± 0.7	72.3 ± 0.2	82.3 ± 0.2	63.3 ± 0.2
LED Output Power of ECFL2 [dBm]	initial	+0.30	-1.60	-0.18	-0.62
	6 months later	+0.36	-1.29	-0.74	-0.77
	7 months later	+0.37	-1.07	-0.77	-0.65
Emission Peak [nm]		653.9	655.5	653.1	651.4
LED Output Power of OTDE [dBm]	initial	-0.1	-1.58	-1.09	-1.30
	6 months later	-0.95	-4.0	-1.15	-2.6
	7 months later	-0.97	-4.04	-1.25	-2.75
Emission Peak [nm]		654.3	653.9	654.9	654.1

Table 1: POF-LAN link performance after 6 months continuous operation; up = upstream (hub to workstation), down = downstream (workstation to hub).

Conclusion

We have shown the 10-Mbit/s-Ethernet operation with LED over seven months in a real POF-LAN-Environment with distances up to 100 m and a BER less than 10^{-9}. Further observation of the power budget limits will produce evidence for the reliability for commercial applications.

References

[1] Hoechst AG, “INFOLITE Polymer Optical Fiber, Product Specification“, 1992

[2] Hewlett Packard, “125 Megabaud Versatile Link; The Versatile Fiber Optic Connection; HFBR-0507 Series“ , Technical Data, 1994