Bi-directional Ethernet link over a single plastic optical fiber using POF couplers

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Abstract

One-port Ethernet transceivers based on low cost 2x2 POF couplers have been developed and tested. A 40 meters point to point bi-directional Ethernet link has been achieved using fabricated transceivers and a single POF. The link presented an optical power budget of 7.3 dB using commercially available LEDs and detectors. A study of the directivity of the couplers has also been performed, showing that backreflected data may limit the performance of the one-port transceivers.

Introduction

In the last years optical fiber based transmission systems have reached the local area network, but their use is essentially restricted to link routers, switches and hubs. Most of the computers are still connected by copper cable due to the extra cost of the glass optical fiber technology, mainly because of the high cost of connectors and splices. POF can be an alternative to substitute copper cable in the final segment of the network, where distances are short and the bandwidth is relatively low. While cost is comparable to copper technology at the same bandwidth, POF is free from electromagnetic interferences and isolates the LAN from potential loops. The Ethernet protocol has become the *de facto* standard in this final segment of the networks, in such a way that nowadays an Ethernet/Fast Ethernet port is integrated in almost every computer. In addition, modern cable modems for Hybrid Fiber Coaxial (HFC) CATV also integrate an Ethernet port to connect home computers to a HFC network. One of the main problems of HFC networks is the ingress noise that is inserted in the upstream path of the link due to electrical noise inside the house. The electrical isolation obtained using optical connections can improve the operation of the upstream channel of HFC networks. This fact, together with the low cost and ease of installation of POF, make this fiber an excellent candidate for wiring the home network [1]. So, a combination of POF and Ethernet/Fast Ethernet hardware should become a key technology in the next years [2].

In this work a bi-directional one-port Ethernet POF transceiver is presented. One-port transceivers are interesting because the user has to connect only one port, avoiding errors in the connection of the emitter-detector ports, and because the link is independent of the different attenuation that two different POFs may have. Several transceivers for single POF bi-directional links have been presented recently [3]. In our case, 2x2 low cost POF couplers fabricated by us [4] have been used to fabricate one port Ethernet transceivers. The two input ports of a POF coupler have been used to connect the emitter and the detector and one output port has been used to maintain the link. The operation of the POF transceivers has been tested, including a study of the directivity of the couplers, which may degrade the reliability of the link by collisions originated by backreflected data.

Description of the bi-directional one-port POF transceiver

The experiment was performed using several POF Ethernet transceivers developed by us, where the two input ports of a 2x2 POF coupler are connected to the optical source and detector of each transceiver, as is shown in figure 1. In this way, light emitted by the optical source is coupled into the two output ports in the forward direction, and light inserted into any of these ports in the backward direction is coupled into the LED and detector. Therefore, only one of the output ports of the POF coupler is able to send and receive data, obtaining a bi-directional single POF link.

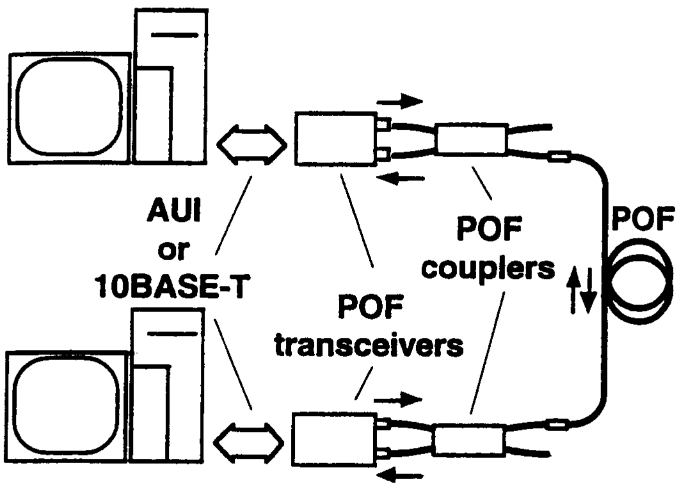

Figure 1.- Scheme of the bi-directional one-port POF link configuration

The POF Ethernet transceivers can support AUI or 10Base-T electrical Ethernet inputs, which are converted to optical signals compatible with plastic optical fibers. The transceivers are based on usual glass fiber optic Ethernet transceivers, where POF based LED (HFBR-1527, 650 nm wavelength) and detector (HFBR-2526, silicon detector), were placed instead of glass fiber optic based devices. The POF Ethernet transceivers were tested and showed that they could maintain a 110 m link without errors, using SI-POF supplied by Hewlett-Packard that has 0.18 dB/m loss. This gives a link power budget of about 19 dB.

A 2x2 POF coupler was used to insert the optical channel into the POF in the forward direction and to receive the optical channel in the backward direction using the same fiber. The optical coupler was fabricated using the method described in [4]. This low-cost method produces POF couplers with insertion losses around 4 dB and near 50% coupling ratio. So, the use of POF couplers limits the length of the link, because each channel suffers about 8 dB extra loss due to the coupling mechanism in both transceivers, plus about 2 dB insertion loss in each fiber-to-fiber connection. It gives rise to a 7 dB power budget for the link using the configuration pointed before, or 40 m maximum link length. Figure 2 shows a link between two computers over a single POF using fabricated AUI-based transceivers and 2x2 POF couplers. Higher lengths can be achieved using fiber with lower losses (50 m for 0.14 dB/m fiber) or a low cost 650 nm visible laser diode as the optical source. Nevertheless, the use of laser diodes may lead to link errors due to an increase of backreflected optical power in the POF coupler, what is going to be analyzed in the next point.

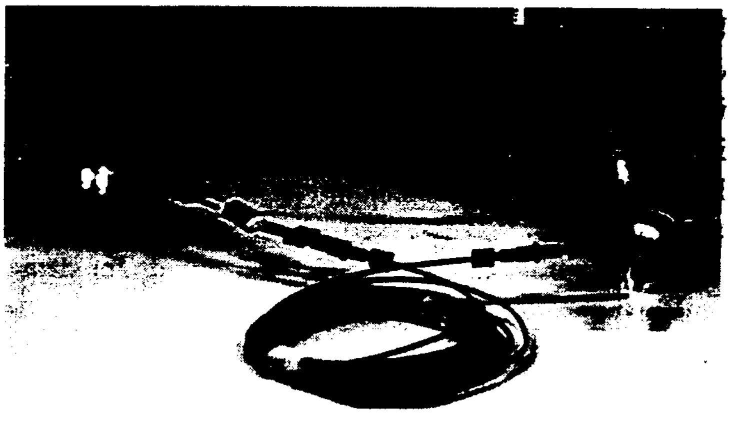

Figure 2.- Bi-directional single POF link using AUI-based Ethernet transceivers.

Results

The couplers used in the experiment were characterized using the optical source of the transceiver and a 1 cm^2 area silicon detector. The results are shown in tables I and II, where all the values are given in dB. Input ports are represented in the left column and output ports in the top row.

Table I: POF coupler 1

input/output	1	2	3	4
1	/	21.5	5.0	3.8
2	22.7	/	4.3	4.5
3	5.3	5.0	/	24.2
4	3.6	4.5	23.5	/

Table II: POF coupler 2

input\output	1	2	3	4
1	/	24.3	6.0	3.9
2	21.9	/	4.1	4.0
3	4.9	3.2	/	21.9
4	4.1	4.0	22.3	/

It can be seen that the insertion loss of the couplers are close to 4 dB, which represents about 8 dB extra loss in the link. The direction of transmission with higher losses will limit the distance of the link, so input and output ports have to be chosen with care using the tables to minimize losses for the two couplers. We have chosen port 1 as the input and port 4 as the output for the coupler 1 (it implies that port 2 has to be the detection port), and ports 4 and 2 have been chosen as the input and output ports for the coupler 2. This represents a power loss of 7.7 dB in the coupler 1 to coupler 2 direction and 7.6 dB in the opposite. The POF used in the link has to be connected to the couplers by means of fiber-to-fiber adapters (HFBR-4505), which have insertion losses of about 2 dB. Therefore, a power loss of 4 dB is added to the link. In summary, we obtain a link with a loss of 11.7 dB that limits the optical power budget to 7.3 dB, or a link distance of 40 m for a 0.18 dB/m POF.

The tables show that directivity for every port is above 21 dB. Thus, data inserted in each port is backreflected due to the fiber-air interface of the output ports, but the reflected data is below the optical power budget of the link in any case. So, when a LED is used, reflections in the POF-air interface of the output ports of the device do not cause interference with the data sent to the device in the backward direction. A mirror was placed near the output port (this which is not used in the link) of one of the POF couplers to test if higher values of backreflected power could degrade transmission. It was observed a link fail when the mirror was about 2 mm from the port, probably due to the collision of backreflected data with the data sent from the other transceiver. Backreflected optical power for this case was measured using a 1 cm^2 area silicon detector, and it was observed that the directivity of the POF coupler had raised to about 19 dB. Therefore, it is necesary to maintain the directivity of the couplers under the optical power budget of the link to avoid collisions that can be originated by backreflected data.

Higher link power budgets can be achieved using a laser diode as the optical source of the transceiver provided that it can couple a bigger amount of optical power into the POF. However, if a laser diode is used, the higher emitted optical power will cause an increase of power in the backward direction, and this may cause collisions in the receiver and oscillations in the laser diode. Therefore, it is necessary to avoid these unwanted reflections in the output ports of the POF coupler increasing its directivity. A low cost 5 mW 650 nm laser diode (Toshiba TOLD9442M) has been used to study the increase in the optical power budget of the link and, therefore, the amount of power that is backreflected in the POF coupler. Using the laser diode, there is an increase of 7 dB in the optical power inserted in the POF, giving rise an optical power budget of 26 dB. Consequently, it is necessary to increase the directivity of the POF coupler about 7 dB to avoid unwanted backreflections. A silica refractive index matching gel (Cargille Optical Gel, nD = 1.46) has been used to reduce the reflection of light in the output ports of the coupler. Measurements show that there is a mean increase of 3.3 dB in the directivity of the coupler when each port is inserted in the gel. It has also been confirmed that the reduction of backreflected optical power is about the same placing the refractive index matching gel between two connectors in a fiber-to-fiber adapter. Hence, if a laser diode is used as the optical source, both output ports have to be refractive index matched to reduce adequately the optical power of the backreflected data under the optical power budget of the link.

Conclusions

In this work a bi-directional Ethernet link over a single POF has been presented. Several POF based Ethernet transceivers have been developed and tested, presenting a 19 dB power budget link. Low cost 2x2 POF couplers have been used to fabricate one-port Ethernet transceivers, which presented an optical power budget of about 7 dB, due to the insertion losses of couplers and fiber-to-fiber adapters. The directivity of the couplers have been investigated since it has been proved that backreflected optical power can degrade the transmission of data. In the case of using a LED as the optical source of the transceivers, it has been shown that the directivity of the couplers is high enough to maintain an error free link. Laser diodes, which emit much higher optical power in the POF and permit higher link lengths, must have the output ports of the POF couplers refractive index matched to avoid collisions.

Acknowledgment

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