Cost-effective hybrid Fast-Ethernet switch for POF networks

J. Mateo[1], F. Villar[1], M.A. Losada[1]

[1] *Group of Photonic Technology, Aragón Institute of Engineering Research (i3A), Universidad de Zaragoza, Zaragoza, Spain,*
jmateo@unizar.es, alosada@unizar.es

Abstract: In previous works, we introduced plastic optical fibers (POF) as a competitive transmission media for industrial, office and home networks. In fact, we proposed that nowadays a good solution for home networks is a daisy chain topology with an optical backbone with several electrical ports to connect the different devices. To implement such a network, low-cost hybrid switches are necessary with at least two optical ports. Therefore, our aim is to assess the feasibility of designing and implementing this kind of switches. Thus, we present in this paper a development of a Fast Ethernet hybrid switch that includes two commercially available optical small form-factor pluggable (SFP) transceivers.

Introduction: Nowadays, the technology is mature enough to afford the digital convergence of Triple-Play (data, image and voice) into the home and the plastic optical fiber can play a very important role in this scenery.[1-3] The market provides the products and technology necessary to satisfy the consumer needs but, at the moment, wiring into homes is not designed for the new technologies. Although the present technology permits to unify the different services into the home, it is necessary a minimum capital investment in home communication networks to envision a future without coaxial and telephone wires. Several technologies try to cover the needs for the user in a homemade network: Wireless, power line communication, UTP copper cables and silica or plastic optical fiber are the main alternatives. Many studies to reveal which of these technologies is better suited for the domestic networks, have been carried out, such as the comparative study we presented two years ago.[4] Now, we are convinced that POF is a cheap, do-it-yourself medium without the impairments of other solutions such as the WiFi.

To be able to develop a home infrastructure, we proposed a personal computer with some extra hardware and software as the central node of a network which will allow the user to enjoy the multimedia content anywhere in the house.[5] The more favorable topologies for this network are either a daisy chain or a tree, as both reduce installation costs and aesthetical impact over built houses. Previous studies and essays have shown that the optical fiber combines a greater number of advantages over the other media, such as wide bandwidth and low-cost.[1-3] However, the connection to electronics equipment is better suited by copper cable. Therefore, in our proposed network, while the backbone is based on standard 1-mm SI-POF operated at a visible wavelength, the final end to the electronics devices is standard RJ45 copper cables. Thus, the media conversion is performed by low-cost transceivers or electro-optical switches with several electrical ports to connect the different devices. In this way, low-cost hybrid switches with at least two optical ports are necessary. Here we present the design and implementation of a hybrid electro-optical switch for Fast Ethernet that includes two commercially available optical small form-factor pluggable (SFP) transceivers. Our aim is to demonstrate the feasibility and viability of building these devices and to test the operation of the optical transceivers. So, with this idea in mind, we have made only one small series of six switches. This small production is the reason why the costs are not competitive with recently developed switches. Several manufacturers[6,7] have implemented devices with similar characteristics, which are now commercially available at lower prices than our switch.

Fig. 1: Optolock® transceiver from Firecomms.

Switch Design: This switch has to be a hybrid device with optical and electrical ports. We have designed the switches using connector-less transceivers commercially available in 2008 for Fast Ethernet and standard 1mm SI-POF. So, our printed circuit board (PCB) design is capable to accommodate either the

Firecomms Optolock® transceiver[8], shown in Figure 1, or the Diemount Optospider™ SFP transceiver[9], shown in Figure 2. Optical ports will connect to the 1mm SI-POF and electric ports to the RJ45 copper cables. The plastic optic fiber ports support half or full duplex configurations eligible by the user, and can be selected like high priority ports. The plug and play copper ports support 10/100Mbps auto-negotiation and auto MDI-MDIX functions that permit to connect devices both in direct and cross cables.

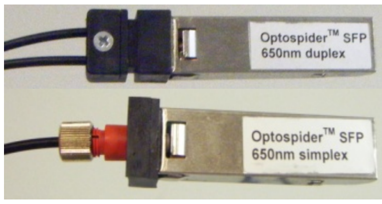

Fig 2: Optospider™ SFP modules from Diemount. Above, the duplex model using two different fibers. Below, module designed for simplex transmission over just one fiber. Both modules work with visible 650nm sources.

The switch core is the integrated circuit IP178C manufactured by IC+, which is capable of managing eight ports where two of them can be fiber connections. This controller has other desirable characteristics: a 1K MAC address support, broadcast storm protection, QoS support, a spanning tree protocol, and an auto MDI-MDIX option that provides versatility for the user. This integrated circuit meets the specifications of the IEEE802.3 standard, which is the Ethernet standard. Ethernet controllers today also comply with later versions such as the IEEE802.3u standard, with the possibility of working with optical fibers, or the IEEE802.3x, which allows full duplex transmission. Its main function is to manage efficiently all traffic between the different ports, avoiding collisions and allocating the bandwidth appropriately.

For the electrical ports, the RJ-45 is the physical interface, widely used to connect structured cabling networks. It has eight electrical connections, which normally are used as the end of twisted pair cables. There are two typical configurations depending on which side the cables are connected. The direct patch cable network is used to connect different devices such as, for example, a computer to a switch. The crossover cable is used to connect two devices that perform the same function, such as two computers. At present, most switches support cross cables to connect to another switch, and certain devices can be equally connected by a direct or a crossover cable, since they are able to use the configuration PC-PC or PC-switch. This feature is known as auto MDI-MDIX. To reduce the size of the device we have limited the number of electrical ports to four instead of the six electrical ports that the controller is able to drive. We will use the 5406203-3 Tyco Electronics, which is a module that contains four RJ45 sockets in a 1x4 configuration as Figure 3 shows.

Fig. 3: Quadruple RJ45 module.

The interface with the electrical ports is made by means of 50Ω resistors with a tolerance of 1% to provide impedance matching in the line. The capacitor, located between resistances, is responsible for rejecting the common mode voltage. A standard integrated inductive coupling is used for the final connection to the RJ45 ports. This module consists of a magnetic primary winding, a coil choke and a secondary winding in a relation 1:1. The choke, with the capacitor, eliminates the common mode voltage that would pass directly to the line. The unused twisted pairs are connected by means of Bob Smith terminations. This circuit is used to avoid possible electromagnetic interference and electrostatic system discharge.

Our optical POF-based ports are SFP transceivers, which act as the input-output devices that connect the controller with the POF network. These devices provide a flexible and cost effective solution for both domestic and small-business networks. They are plug and play devices which are recognized by the system simply by connecting them. This solution is very flexible as other SFP devices designed for other fiber types can be used instead to increase bandwidth or link distance, in order to fulfill the user needs. On the other hand, the design can accommodate the Optolock® Firecomms transceivers as well, thus offering the chance to test other kind of transceivers.

The interface of the IP178C controller with the optical ports requires an offset level to communicate with the opto-electronic transceivers. If the transceiver incorporates an internal decoupling capacitor, only an offset level has to be added at the beginning of the driver for the differential pairs. If the transceiver does not include internal capacitors, they must be incorporated. The differential transmitter lines (TX + and TX-) are connected to 1.9V by 100Ω resistors. At the differential reception lines, we introduced a 1KΩ resistor for both lines (RX+ and RX-) connected to 1.9V.

The switch is powered with a commercial AC/DC transformer of 5V and this voltage is lowered to 3.3V internally by means of a regulator. Equipment working at high rates generates switching noise in the power lines due to load and unload of the capacitors of the internal and external circuits. The instantaneous current generated by the flanks of the rising and falling outputs causes the power lines fluctuate. This effect can cause the voltage to exceed the recommended conditions or to generate false signals, which could be a serious problem. To avoid it, a very careful decoupling and filtering of the power near each component is required.

The IP178C controls three LEDs for each port. In total, there are six columns of three vertically arranged LEDs, plus the power indicator LED. The upper LEDs are on if the controller detects that the port is connected, and blink when data is transmitted. The middle LEDs light up only if the speed is 100 Mbps. Finally, the LEDs below are on if the connection is full-duplex, but not when it is half-duplex.

The IP178C has two configuration modes, one via EEPROM and the other through hardware inputs whose levels determine the controller operation. In this case, we have used dip switches jointly with resistances to configure the various functions setting the different pins to 1 or to 0. However, the implementation has been prepared also to be able to accommodate an EEPROM, eventually. In that case, only the controller pin 53 has to be changed to a high level by a jumper. Finally, we have added a button to reset the switch.

We made a two-layer design, where the signal traces are located at the top layer. The power, and the signal traces that could not be placed on the top layer, are on the bottom layer.

Fig 4: The top images show the final design of the switch which is inside the black box. The bottom picture shows different PCBs in different stages of production.

Data tracks were designed as micro strip lines to ensure the impedance matching of the differential pairs for transmission and reception. The width of the track was fixed to 10 mils and the space between tracks to 6 mils. To reduce propagation delays, signal loss, and noise, the present layout of the tracks has been carefully considered. First, interference of the digital signals, such as clock signal, with analog transmission and reception signals must be avoided. Thus, power tracks must be wide enough to be able to carry the current required for the circuit. The clock signal transmission and reception traces must have an adequate width. The length of each track should not exceed a 5% of the wavelength. For the Fast Ethernet signal with a speed of 125 Mbps, the maximum distance is 12 cm. The minimum distance between transmission and reception pairs must be wide enough, and in our case was set to 0.8 mm.

The whole design has been constrained to fit inside a standard commercial box of 130x96 mm as shown in the upper images of Figure 4. The lower image shows the implementation of the PCB in different stages of production.

Discussion: The main advantage of the 1mm core POFs is that they are able to accept high light powers without sophisticated connections, which makes installation an easy process. In fact, the use of visible light makes fiber termination and connection so simple that can be performed by an unskilled user. Moreover, POFs can stand curvatures with lower losses than glass fibers. On the other hand, its high attenuation limits its working distance up to 50 meters, but in a standard house and with a daisy chain topology this is more than enough.

The final costs of each switch are, approximately, 128 €, where the transceivers have not been included as the user should be able to chose those more convenient for his/her network application. Half of the costs correspond to the PCB and to the assembly of the components. This extraordinary cost is mainly due to the fact that only a small sample of switches has been manufactured. If a higher number of switches were produced, their individual costs would be considerable lower as the PCB fixed initial overhead would be shared between them and the assembly would be fully automatic in a larger batch.

Once corrected the first unavoidable design errors in the first prototype, the small series of switches have demonstrated an extremely robust performance. Its performance has been tested using a link of 25m of PMMA 1mm SI-POF between them, giving an error free performance. In fact, they are now working in our laboratory where they are part of our own private network.

Conclusions: We have designed a hybrid electro-optical switch for Fast Ethernet to use with standard 1mm SI-POF based networks, and implemented a sample of six units. Its cost is not too high, having into account that we have only built only a small number of units although it is higher than those commercially available. If we set out to implement a greater number, it would be more cost-effective. Our switches are now working in a private network installed in our laboratory[5]. This switch can accommodate two types of electro-optical transceivers, and thus, it can also be exploited to test other commercial POF transceivers.

Acknowledgements: This work was supported by the Spanish Ministry for Science and Technology under grant TEC2006-13273-C03-02.

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