Draft

White Paper

Present State-of-the-art of Plastic Optical Fiber (POF) Components and Systems

Prepared for:

The TIA TR-42 Engineering Committee on User Premises Telecommunications Infrastructure

Prepared by:

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1.0 Introduction

Several years ago, a presentation was made by Boston Optical Fiber to the TIA TR-42 subcommittee on Residential and Commercial Wiring concerning a new plastic optical fiber (POF) technology, a PMMA graded index POF (GI-POF). Since then the POF industry has grown and new technology has been developed. This white paper has been prepared by the Plastic Optic Fiber Trade Organization (POFTO) with a membership of over 50 worldwide members.

The goal of POFTO is the promotion of the POF technology thru:

- Participation and representation of POFTO members at standards meetings
- Participation at trade shows
- Other means and methods

It is for this reason that POFTO has prepared this white paper on "The State-of-the-art" of plastic optical fibers, components and systems.

POFTO and its members plan to become active participants in TIA standards activities in the future. All communications can be made to :

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Plastic optical fibers can be used for a number of applications such as light transmission for signs and illumination, sensors, and data communications. This paper focuses only on the data communications aspects.

2.0 Recent Technical POF Developments

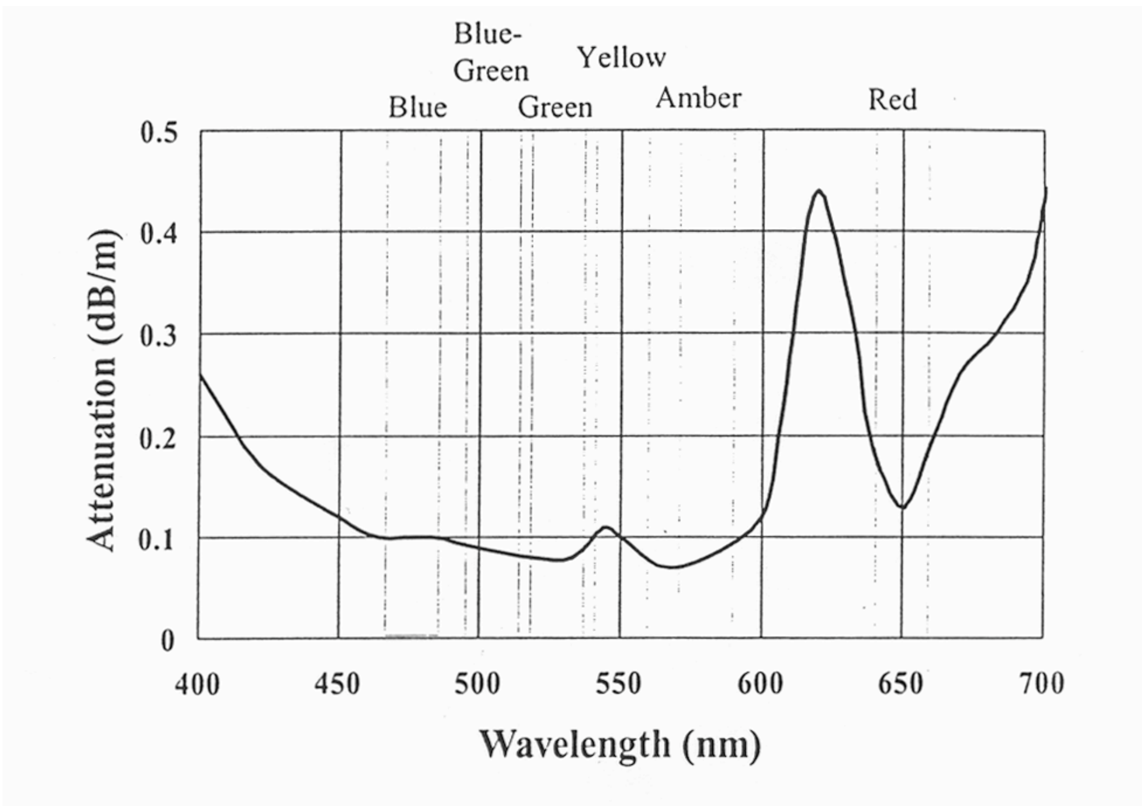
Until recently, plastic optical fibers were limited in both transmission speed and distance. Equipment for speeds of up to 400 Mbps and 50 meters using step index PMMA fibers are readily available today and meet most needs in industrial and consumer electronics. New graded index POF make it possible to increase the speeds to over 1 Gbps which is suitable for applications such as gigabit ethernet and Digital Video Interface. To address the distance issue, a new perfluorinated fiber (PF) has been developed with losses of 25 dB/km with the potential of 10 dB/km over the wavelength range of 650nm to 1300nm. In addition, the PF fiber can be made with graded index profiles and have bandwidths of greater than 4GHz-100m. The following is a short description of existing POF fiber technology.

2.1 Step Index PMMA POF

Plastic optical fibers for data transmission until recently were limited to step index PMMA fibers that had bandwidths of 38MHz-100m (Mitsubishi Eska). More recent results by Mitsubishi with an Eska-Mega fiber shows a three fold increase in bandwidth to 105MHz-100m[1]. Increases in bandwidth are also possible with the use of dual step index (DSI), multi-step index (MS) profiles, multi-core (MC), or combinations of these.

A typical loss spectrum of a SI-PMMA fiber is shown in figure 1. Sources both LEDs and laser diodes in the 650nm window have been available for some time. It is only recently that LED and Resonant Cavity LEDs (RC-LEDs) sources have become available in the 520nm and 580nm windows.

Figure 1: Typical Spectrum of PMMA Fiber



In October of 2003, the POF Applications Center (POFAC) in Nurenberg, Germany submitted to the VDI/NDE working group "Ethernet over POF," a specification proposal of 125 Mbps (fast ethernet) over 100m using a SI-PMMA POF. The proposed link used a 520nm LED source and a Dual Step Index (DSI) PMMA fiber.

2.2 Graded Index POF

After a number of different companies have attempted to market a Graded Index POF (GI-POF) made from PMMA, Fuji Film announced a GI-POF and Digital Video Interface (DVI) link using a 780nm VCSEL in 2003. The fiber, called Lumistar, used for the DVI link has a diameter of 300 microns and is capable of transmitting the DVI signal over 30 meters at 1.65 Gbps. Several manufacturers in the U.S. and Korea are developing GI-POF products using PMMA

2.3 Perfluorinated Graded Index POF (GI-POF)

2.3.1 Asahi Glass Co.

Asahi Glass of Japan together with Keio University has developed a perfluorinated polymer graded index POF with losses less than 25 dB/km over the 850-1300nm range. In June of 2000, Asahi Glass formed the Lucina Division to commercialize the fiber. The perfluorinated material is called CYTOP. The fiber has the following characteristics:

- Core/fiber diameter: 120/500 microns
- Bandwidth: 1 Gbps at 200m (850nm)
- Loss: 22-40 dB/km (850-1300nm)
- Operating temperature: -10 to 60°C
- Storage temperature: -20 to 70°C

Asahi has demonstrated that its possible to transmit 2.5 Gbps over 100 meters.

A number of "hero" experiments have been done using the Lucina fiber. These results are shown in Table 1.

Table 1: PF GI-POF Transmission Records

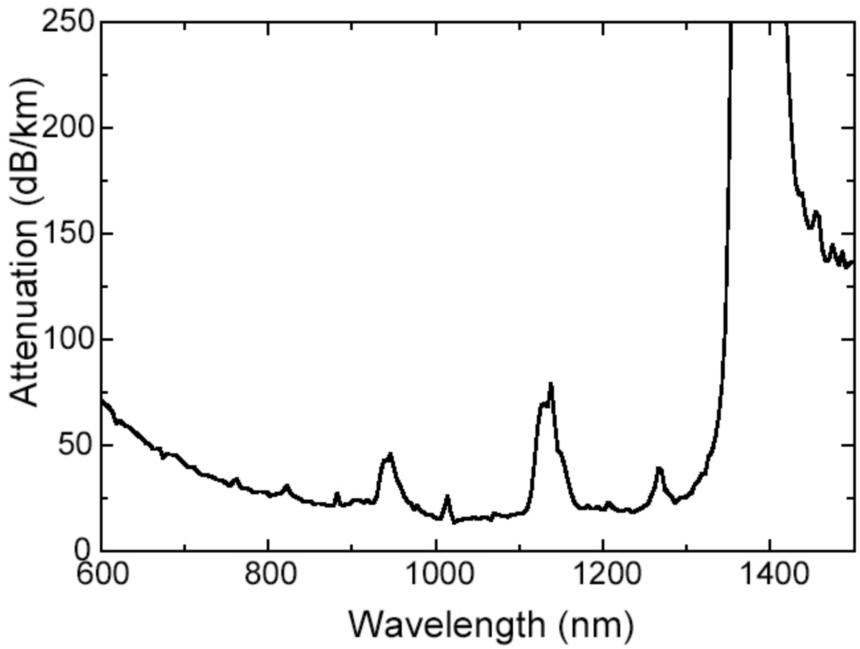
Year	Bitrate (Gbit/s)	Distance (m)	Wavelength (nm)	Organization
1997	2.5	200	1300	Fujitsu
1998	5	200	1310	Eindh. Univ.
1998	2.5	300	645	Eindh. Univ.
1998	2.5	550	1310	Eindh. Univ.
1999	2.5	550	840	Eindh. Univ.
1999	11	100	1300	Lucent
1999	7	80	950	Ulm. Univ.
1999	3λ x 2.5	200	645, 840, 1300	Eindh. Univ.
2000	2λ x 2.5	456	840, 1300	Eindh. Univ.
2001	1.25	990	840	Eindh. Univ.
2002	1.25	1006	1300	Eindh. Univ.
Source: G,D, Khue et al. POF 2000				

A paper by Asahi Glass will be presented at POF World 2004 in San Jose, June 23-25, 2004. In this paper, Asahi identifies a complete product line for Lucina applications such as cables, connectors, optical wall outlets, splice boxes, connectors, Ethernet and Fiber channel transceivers, media converters, and handling tools. The paper also reviews the latest PF GI-POF applications in Japan.

2.3.2 OFS Laboratories

OFS Laboratories has been developing PF GI-POF under a license from Asahi Glass since 2000. It has developed a continuous extrusion process for manufacturing the fiber. A typical spectral attenuation for the extended PF GI-POF is shown in figure 2. It should be noted that the loss is less than 50 dB/km from 650nm to 1300nm. OFS Labs has reported a measured bandwidth of greater than 400MHz-km.

Figure 2: Spectral Attenuation of Extruded GI-POF



3.0 Standardization of POF

At present, step index POF is standardized by the International Electrotechnical Commission (IEC) as the A4 category of fibers. This category contains 4 types (families A4a-A4d) of SI-POF having core diameters ranging from 490 microns to 980 microns. This standard also calls out other dimensional requirements for these fibers, as well as minimum mechanical and transmission properties. The existing IEC POF standards do not specify any environmental requirements, however.

OFS and Nexans have recently proposed to modify the A4 category fiber standards to include PF GI-POF. According to this proposal, four new fiber families (A4e-A4h) will be added to the A4 category. As shown in table 2, these families will have core diameters of 500 µm, 200 µm, 120 µm, and 62.5 µm, and are intended to serve a wide variety of applications ranging from consumer electronics to multi-Gb/s data communication.

Table 2: Proposed Families of GI-POF

Family	Cladding Diameter (µm)	Core Diameter (µm)	Attenuation at 850 nm (dB/km)	Bandwidth (MHz-km)
A4e	750	500	40	150-300
A4f	490	200	40	150-400
A4g	490	120	33	188-500
A4h	250	62.5	33	188-500

Since these applications employ a wide variety of optical sources and receivers, a correspondingly wide range of fiber core diameters is also needed.

The transmission requirements for the new families of POF are much more stringent than those for the existing families of POF. While the larger core

GI-POF families (typically used at relatively low speeds) are specified to have a maximum attenuation of 40 dB/km at 850nm, the smaller core families are specified with a maximum attenuation of 33 dB/km. In all cases, the range of specifiable bandwidths is greater than 150MHz-km. By comparison, the existing standards for step index fiber specify only 130 dB/km attenuation, and bandwidths in the range 105MHz-100m.

Because the new families of PF GI-POF guarantee qualitatively higher performance, they may be used with confidence in wide variety of new areas, including high-speed premises datacom and central office telecom applications. Hence, it is anticipated that future standards for GI-POF wll grow from fiber and cable standards to application standards such as Gigabit Ethernet.

4.0 Sources

Sources for POF transmitters include LEDs, laser diodes, resonant cavity LEDs (RC-LEDs), and VCSELs. LEDs have been the main sources for POF links due to their low cost, however, recent developments in Resonant Cavity LEDs and soon to be introduced VCSELs at 650nm provide a broader mix of sources for higher speeds for systems designers. Table 3 lists the various types of sources and compare their state of development

Table 3: Properties

Property	LED	SLED	LD	VCSEL	RC-LED	NRC-LED
Availability 650nm	Yes	Yes	Yes	Samples	Samples	No
570	Yes	No	No	No	Samples	No
520	Yes	No	No	No	No	No
Modulation	250 Mbps	250 Mbps	4 Gbps	1 Gbps	600 Gbps	1.2Gbps

5.0 Applications

Despite the advances in higher speeds and longer distances (100 meters and higher), there still exists a number of applications for less than 100 meters for consumer electronics, home networks, medical and industrial controls. The IEEE 1394 has endorsed SI-POF to meet this need with the adoption of the 1394b standard at 50m length. Prior to this, the ATM Forum has recognized the need for 50 meter at 155 Mbps. The POFTO forecasts a number of applications within the home of less than 50 meters for DAI, DVI and other consumer applications.

An exciting application is the potential of 1394b in automobiles and the home whose devices from the home can be used in the auto and vice versa. The auto market is described in the next section.

5.1 Killer Application

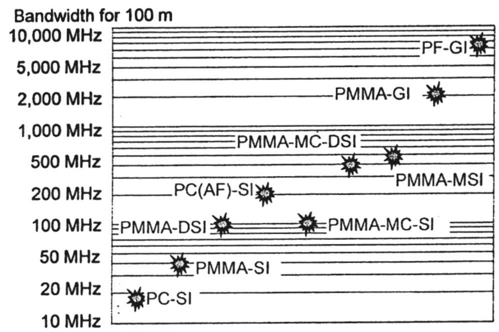
The POF industry has a "killer application" in the auto industry. Daimler-Benz has spearheaded a group of automobile manufacturers and suppliers to develop a POF data bus standard for automobiles called MOST (Media Oriented Systems Transport). The objective is to have a standard that all auto manufacturers can purchase against and, hence, reap the benefits of volume production. The initial data buses operate at 28 Mbps, but are expected to increase to 56 Mbps and to 155 Mbps. By the end of 2004, there will be 15 million optical nodes installed in over 16 models of European cars. By 2005, the number is expected to be 10 million nodes per year. It is now possible to purchase a TIR press for $7.00 and the cost is expected to be reduced to $3.00.

The economies of scale should also benefit other industries such as consumer electronics, home wiring, medical electronics and industrial controls.

6.0 Summary

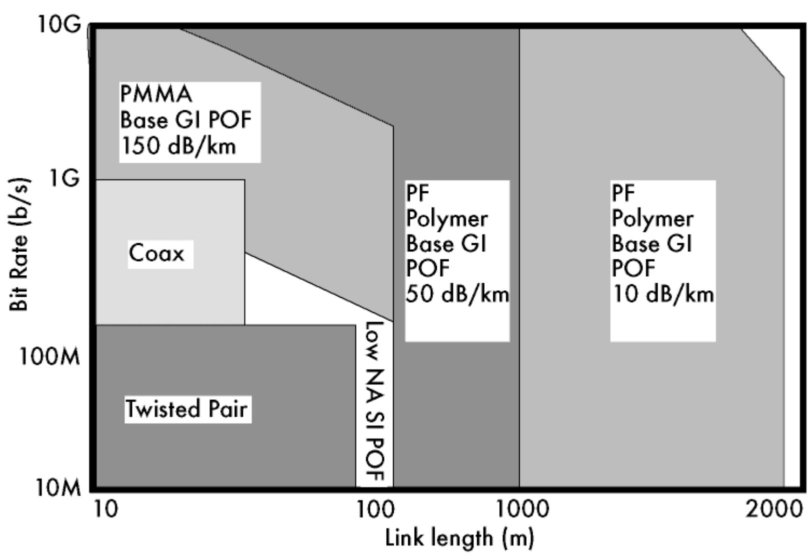
The myth that plastic optical fibers must operate at 100 meters or more is now a thing of the past. POFTO has identified a number of consumer and in-home applications where short distance data links are required as low as a few meters. The development of plastic optical fiber technologies is moving ahead at a fast pace. Together with the "killer application" of the auto industry, the realization of POF as a low cost transmission media is upon us. Figure 3 summarizes the increase in bandwidth that has occurred over the past several years.

Figure 3: Index Profiles of POF and Bandwidth



There are many large worldwide organizations that want to implement applications using POF technology if the TIA standards would support a 50m distance.

Figure 4: Bit Rate v. Length of Link



References

[1]. T. Yoshimura, and Y Koyamada. "Analysis of Transmission Bandwidth characteristicsof SI-POF." POF-2003 proceedings. P 119, September 15-17, 2003 in Seattle.
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[2]. T. Nakamura et al. "VCSELs for Home Networks - Applications of 780nm VCSEL for POF." POF-2003 proceedings. P 161, September 15-17, 2003 in Seattle.

[3.] L. Blyler, V.R. White, R. Ratagini, and M. Park. "Perfluorinated POF: out of the lab, into the real world." POF-2003 proceedings. P 16, September 15-17, 2003 in Seattle.

