

Plastic Optical Fibers Branch Out

When people hear of optical fibers, they immediately think of glass. Few people, including professionals in the business, know about plastic optical fibers (POFs), which predate those made of glass. Because glass fibers have certain advantages, they have dominated the market, while POFs have remained largely in the background.

Recent developments in technology and applications, however, have burnished the image of POFs, and they are finding a larger market with technology companies worldwide. Today, a new enthusiasm permeates the plastics side of optical fibers.

Profile

POFs compete with copper wires, coaxial cables, glass optical fibers, and wireless, and they require a transmitter, receiver, cables, and connectors similar to those used in glass optical-fiber links (see *The Industrial Physicist*, February/March 2002, pp. 18–21).

Manufacturers form POFs out of plastic materials such as polystyrene, polycarbonates, and poly(methyl methacrylate) (PMMA). These materials have transmission windows in the visible range (520–780 nm). However, the loss of light transmitted at these wavelengths is high, ranging from 150 dB/km for PMMA to 1,000 dB/km for polystyrene and polycarbonates. These losses often handicap plastic fibers in competing against high-quality glass fibers, which have losses of 0.2 dB/km for a single-mode fiber and less than 3 dB/km for multimode fibers.

Hence, plastic fibers have been relegated to short-distance applications, typically of a few hundred meters or less, compared with the hundreds of kilometers for glass. Nonetheless, POFs have found many appli-

cations in areas such as industrial controls, automobiles, sensors for detecting high-energy particles, signs, illumination (including lighting works of art in museums), and short

electrical-to-optical and optical-to-electrical converters, respectively. More complicated data-link configurations include rings (each receiver on a network responds only to its address), stars (signals go to a hub for relay), and meshes (all receivers are interconnected in a manner similar to the Internet). As when glass-fiber systems were introduced, simple point-to-point POF links were installed first, followed by rings and stars. Today, fashion favors a combination of rings and meshes.

Advantages

Certain users find POF systems provide benefits compared to glass fibers, which include:

- simpler and less expensive components,
- lighter weight,
- operation in the visible,
- greater flexibility,
- immunity to electromagnetic interference (EMI),
- ease in handling and connecting (POF diameters are 1 mm compared with 8–100 mm for glass),
- use of simple and inexpensive test equipment, and
- greater safety than glass fibers or fiber slivers that require a laser light source.

With these advantages come disadvantages that researchers and manufacturers are working to overcome. They include:

- high loss during transmission,
- a small number of providers of total systems,
- a lack of standards,
- a lack of awareness among users of how to install and design with POFs, and
- limited production, which has kept customers from realizing the full potential of POFs.

The high-loss problem is being addressed with new perfluorinated polymer materials, which have brought losses down to poten-

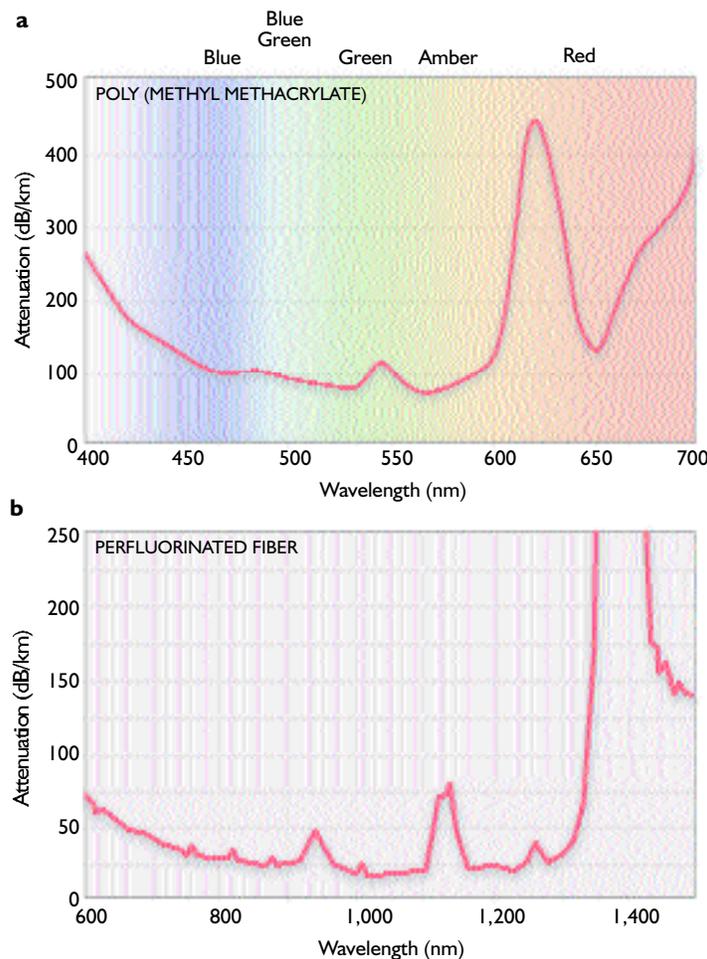


Figure 1. Loss spectrum for a poly(methyl methacrylate) fiber (a) shows minimums at 530, 570, and 650 nm, all in the visible range. Loss spectrum for a perfluorinated fiber (b) is broader (650 to 1,300 nm) and the loss is less than 50 dB/km.

data links. Basically, POF applications divide into data-communication and non-data applications (sensors and signs, for example). Today, the surge in POF production stems from its use in data transmission.

Data transmission

In its simplest form, a POF data link consists of a transmitter, receiver, cable, and connectors. The transmitters and receivers are

tially 10 dB/km; and European automobile manufacturers have united to solve the production-volume issue. Table 1 compares the different transmission media—glass, plastic, and copper.

Loss and bandwidth

The main attributes of any transmission medium are the length over which it can transmit and the speed over that length. Loss of signal strength in an optical fiber can result from absorption or scattering of the light. Absorption is caused by impurities in the fiber, such as metals and water molecules. Light can scatter off impurities in the material, defects in the fiber such as voids, and at core-cladding interfaces and end faces.

Each of these loss mechanisms is a function of the wavelength. Figure 1a shows a typical loss curve for a PMMA fiber. For this loss spectrum, the transmission windows are 530, 570, and 650 nm, all in the visible range. The window at 650 nm is narrow and, hence, could cause problems if a 650-nm source shifted with temperature. The windows at 530 and 570 nm are broader and, thus, less sensitive to shifts in source wavelength resulting from temperature changes. Note that the losses of 125 dB/km at 650 nm and of less than 90 dB/km at 530 and 570 nm limit the use of PMMA plastic fibers for transmitting light to less than 100 m.

Newer plastic fibers made from perfluorinated polymers exhibit greater transmission of light over a wider wavelength range. Figure 1b shows a typical loss spectrum for a perfluorinated fiber. Compared with the loss spectrum of PMMA, perfluorinated polymer fiber has two notable features. First, its spectrum ranges from 650 to 1,300 nm, and, second, the loss is less than 50 dB/km over this wavelength range. This reduction in loss allows fiber links made from this material of up to several kilometers. Thus, perfluorinated fiber overcomes the distance limitation of PMMA, and it can operate using the less expensive

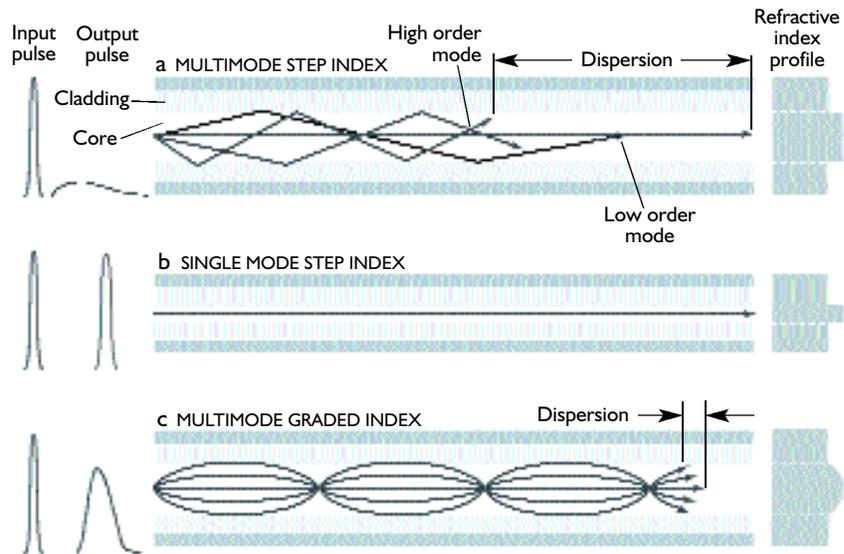


Figure 2. In optical fiber, light is reflected at the interface between the cladding and the core, which has a higher refractive index. Step-index multimode fibers (a) have the lowest bandwidth (highest number of pulses from a modulated light source that a receiver can detect). Reducing the diameter of the fiber (b) reduces the dispersion and increases the bandwidth. A graded-index fiber (c) has the highest index of refraction at the center, and medium bandwidth.

components developed for glass optical fibers at 850 to 1,300 nm.

An optical fiber's bandwidth is the highest number of pulses from a modulated light source that a receiver can detect. Light

at the core-cladding interface. Each ray is considered a mode.

Fiber bandwidth can be increased by reducing the number of modes or by changing the index-of-refraction profile. Reducing the diameter of a fiber allows it to transmit only a few modes, and yields what is called a single-mode fiber, which has the lowest dispersion and, hence, the largest bandwidth. Most POFs have a uniform, or step, index of refraction that is the same across the width of the fiber, and step-index multimode fibers have the lowest bandwidth. In a graded-index fiber, the index of refraction is highest at the center of the fiber and, thus, its profile has a parabolic shape. A graded-index fiber has a medium bandwidth.

Various types of plastic fibers can be manufactured with step-index or graded-index cores using PMMA or perfluorinated polymers.

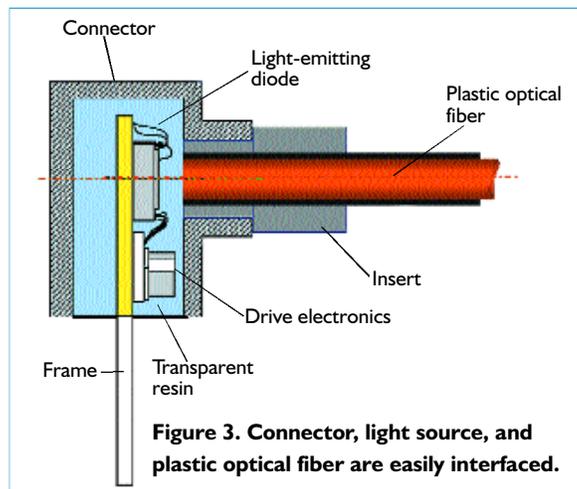


Figure 3. Connector, light source, and plastic optical fiber are easily interfaced.

pulses can suffer broadening (dispersion) because of the different paths that light rays can take as they move along the fiber (Figure 2). There are two ways to characterize light transmission in a fiber: classical ray tracing and the wave nature of light. A fiber consists of a core and cladding, with the core's index of refraction greater than that of the cladding. Containment of light in a fiber results from the reflection of light

Light sources

Several types of light sources can transmit data through POFs, including light-emitting diodes (LEDs), laser diodes, and vertical-cavity surface-emitting laser (VCSELs) diodes. These sources are compared in Table 2 for PMMA plastic fibers. As noted above, the three transmission win-

TABLE 1. COMPARISON OF PLASTIC OPTICAL FIBER, GLASS OPTICAL FIBER, AND COPPER WIRE

	PLASTIC	GLASS	COPPER
Component costs	Potentially low	More expensive	Low
Loss	High-medium (short distance)	Medium-low (long distance)	High
Connections	Easy to connect, requires little training or special tools	Takes longer, requires special tools and training	High
Handling	Easy	Requires training and care	Easy
Flexibility	Flexible	Brittle	Flexible
Wavelength operating range	Visible	Infrared	NA
Numerical aperture	High (0.4)	Low (0.1–0.2)	NA
Bandwidth	High (11 Gbps over 100 m)	Large (40 Gbps)	Limited to 100 m at 100 Mbps
Test equipment	Low cost	Expensive	High
System costs	Low overall	High	Medium

downs for PMMA optical fibers are 530, 570 and 650 nm. LEDs, including surface-light-emitting diodes, can be modulated at speeds of up to 250 megabits per second (Mb/s) and laser diodes up to 4 gigabits per second (Gb/s). VCSELs at 650 nm are still in the development stage, but new resonant-cavity and near-resonant-cavity sources can be modulated at speeds of up to 600 Mb/s and 1.2 Gb/s, respectively.

Perfluorinated fibers, which can operate at wavelengths from 650 to 1,300 nm, work with the light sources developed for 650-nm POFs and the 850- and 1,300-nm laser diodes used with glass optical fibers, which can transmit up to 10 Gb/s.

Because POFs have larger diameters (~1 mm) than glass fibers (8–100 μm), their connectors are less complex, cost less, and are less likely to suffer damage than connectors for glass optical fibers. The reduced damage risks result from POF connectors undergoing less lateral offset and

angular misalignment, and being exposed to less dirt than glass connectors. Because POF connectors have lower tolerances, makers can mold them from inexpensive plastics rather than the precision-machined stainless steel or ceramics that glass fibers require. Finally, because of the ease of coupling light from a light source, it is possible to embed the source and drive electronics into the connector housing (Figure 3), such as for transceivers used in automotive and consumer products.

Applications

Market researchers project a compound annual growth in POF sales of more than 20% from 2003 through 2006 (Table 3). Unlike glass optical fibers, which are mainly used in telecommunications, POFs have applications in many industries. Thus, a slowdown in the telecommunications field can have a less severe impact.

The two major applications of POFs are

in the industrial-controls and automotive fields. Controls remained the biggest and most stable market for the POF industry until last year, when sales to automotive companies rose to become the single largest source of revenue for POF makers. The main driver for POF in the industrial-controls market is the need for data links that resist EMI caused by high-voltage and high-current devices, such as arc welders, and high-voltage apparatuses, such as X-ray machines and ion-implantation units. Today, the major source of excitement in the POF business lies in the innovative uses of its products by automobile companies.

Automobiles

Promoters of new technologies look for “killer” applications that would make the launch of their product a huge success. For POFs, the automobile industry supplied the needed killer application. In 2000, German auto manufacturer Daimler-Benz recognized that the increasing use of digital devices in automobiles increased the weight, susceptibility to EMI, and complexity of wiring harnesses. Until recently, each auto manufacturer developed its own proprietary wiring standards, which hampered them from achieving the economies of scale provided by mass production. Daimler-Benz realized that the way to reduce costs was to develop and buy to a common standard, and its analysis indicated that POF-ring networks would meet the needs of future automobiles.

The auto maker convinced six other European auto manufacturers, including BMW and Volkswagen, to join it in developing a standard called MOST (Media Orientated Systems Transport) and to agree to purchase against the standard. The seven companies also formed an organization called the MOST Cooperation to coordinate the standard’s development and promotion. The MOST Cooperation now consists of 16 auto manufacturers, including General Motors, and more than 60 POF suppliers worldwide.

At the end of 2003, only 24 months after the introduction of the first vehicles with POF networks, 19 European models came equipped with POF data buses. The num-

TABLE 2. ABILITY OF VARIOUS LIGHT SOURCES TO TRANSMIT THROUGH POLY (METHYL METHACRYLATE) OPTICAL FIBER

Wavelength, nm	Light-emitting diodes	Surface-light-emitting diodes	Laser diodes	Vertical-cavity surface-emitting diodes	Resonant-cavity light-emitting diodes	Near-resonant-cavity light-emitting diodes
530	Yes	No	No	No	No	No
570	Yes	No	No	No	Samples	No
650	Yes	Yes	Yes	Samples	Samples	No
Modulation	250 Mbps	250 Mbps	4 Gbps	1 Gbps	600 bps	1.3 Gbps

Source: Firecomms Ltd., 2003

TABLE 3. SERVED AVAILABLE MARKET FOR PLASTIC OPTICAL FIBER IN VARIOUS FIELDS 2003–2008, \$ MILLIONS (TRANSMITTERS, RECEIVERS, CONNECTORS, AND CABLE)

YEAR	Premise wiring	Inter-connections	Consumer	Industrial	Auto	Medical	TOTAL (US \$)
2003	20	46	157	150	187	55	615
2004	26	54	193	176	262	64	775
2005	43	73	228	212	335	73	964
2006	67	81	269	233	394	84	1,128
2007	89	102	300	278	473	94	1,336
2008	117	124	374	328	567	105	1,615

Source: Beach Communications

ber of terminals, or nodes, in the vehicles sold totaled 9.5 million, and 15 million nodes per year are expected to be installed from 2005 onward.

The original MOST system was designed for 25 Mb/s. The next generation will transmit at 50 Mb/s, and the speed is planned to increase to 150 Mb/s by 2006.

Although MOST was developed for non-mission-critical applications in automobiles, BMW also developed a separate, 10-Mb/s POF star network, called Byteflight, for critical elements such as airbag sensors. BMW now has 7 million Byteflight transceivers installed in its vehicles. A third auto network now under consideration, called Flexray, would use POFs as part of an automotive fly-by-light system. Flexray, for example, would replace the mechanical linkage between the brake pedal and brakes with a plastic fiber. When a driver presses on the brake pedal, the resulting force would be converted to a light signal and transmitted to an actuator, which would convert the signal and apply the correct amount of braking to the wheels.

The combination of an accepted standard and the agreement by a group of auto manufacturers to purchase against the standard has created the economies of scale needed by the industry. A transceiver for the MOST system operating at 25 Mb/s presently costs automakers \$4.50, and that price is expected to fall to \$3.00 in 2006, when the speed increases to 150 Mb/s. Similar transmitters for glass optical-fiber systems would cost \$50–100.

In the United States and Japan, automobile manufacturers are planning a more advanced system that would operate at 400 Mb/s using the IBD-1394 standard. This system is expected to be compatible with the MOST standard.

Future prospects

Some writers have characterized POF as

the type of innovation that Clayton M. Christensen termed a disruptive technology in his book *The Innovator's Dilemma* (Harvard Business School Press: Boston, 1997, 225 pp.). Typically, such technologies are significantly less expensive and are ones that established companies could develop, but the companies cannot decide whether the effort is worth the necessary resources or how to market the product. The history of POFs exhibits some of the characteristics described by Christensen: a developing technology, low cost, a lack of initial applications, manufacturers who followed the high-end uses recommended by their customers, and a lack of awareness by end users.

It remains only a matter of time before the benefits of large-scale production in the auto industry start to permeate consumer electronics, medical instruments, and other fields, and bring the benefits and cost structure of plastic optical fibers to bear on these industries.

Further reading

Information Gatekeepers, Inc., provides a POF primer and glossary, available at www.igigroup.com.

MOST Cooperation. *MOST Technology*; available at www.mostcooperation.com.

The Plastic Optical Fiber Trade Organization has inexpensive packages of POF articles and technical papers available at www.pofto.com.

Weinert, A. *Plastic Optical Fibers: Principles, Compounds, Installation*; Wiley-VCH: Weinheim, 1999; 154 pp. 

B I O G R A P H Y

Paul Polishuk is president of Information Gatekeepers, Inc., a telecommunications publishing and consulting company, and co-chairman of the Plastic Optical Fiber Trade Organization (ppolishuk@igigroup.com).