Polymer Optical Fiber for EtherNet/IP Networks

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Abstract:
As EtherNet/IP moves into the machine area, environmental conditions become a concern. In some applications were EMI is high, fiber cabling can provide a higher degree of noise immunity. In the past, the total cost of ownership using fiber is considerably greater than the copper variant. This has hindered the migration of fiber on to the factory floor. With recent breakthroughs in plastics technologies, Polymer Optical Fiber has become a viable solution for on machine cabling. Recently polymers have advanced, providing high temperature, low loss solutions for Polymer optical fiber (POF). Polymer optical fibers can be installed and terminated in the field with little to no training using standard tools. Network dependant interfaces using POF technology cost about the same as their copper counterparts. This paper describes the components, technology and gains associated with designing and deploying Ethernet/IP networks using POF at the Physical Layer.

Body:
Polymer Optical Fiber (POF) will be part of the ODVA EtherNet/IP specification as of the release Volume 2, Ed 1.6 due out fall of 2008. The specification will provide details for the fiber and references to connectors and a connector-less transceiver. Polymer Optical Fiber is not new to the market. It was first introduced several years ago for use in automobiles as a communication bus. Since then, it has expanded into a multimedia communications bus for automobiles and employed as light guides in sensors for on machine automation. The recent developments in plastics have extended the temperature range and the frequency bandwidth to make it possible to be used in high speed networks such as Ethernet 100Base-FX. POF has a very low total cost of ownership when you consider tools, installation time and material costs. The connector installation of POF connectors is very simple and can be adequately terminated with little or no training and very inexpensive tools. Below are examples of cable preparation and connector installation tools.

Figure 1 Cable/Connector Installation Tools

The tradeoff for simplicity is distance. The channel lengths of POF systems are limited to 55 meters (180 feet). The reduced length is adequate for most machine applications.

Determination of fiber insertion loss (attenuation) at room temperature.

The method for determining the insertion loss of an known length of fiber is called the cut back method. This method produced slightly higher attenuation results. The method uses two lengths of fiber cut from the same fiber, 2 meter and 100 meter. The attenuation is then determined by the following relationship.

$$\alpha = \frac{10^4}{(L_0 - L_i)} \cdot \log\left(\frac{P_i}{P_0}\right) \quad \text{dB/km}$$

Where L0 equals the length of the reference cable (usually 1-2meters) and Li equals the length to be measured (usually 100 X the reference cable). P0 equals the insertion loss in dB of the reference cable and Pi equals the insertion loss in dB of the cable to be measured.

Polishing

Connectors are optional with POF, here are several transceivers on the market that do not require connectors, see figure 2 below. These transceivers capture the fiber by clamping down securely on the fiber jacket. Unfortunately they are very much fiber diameter dependant. They however do integrate into a channel with multiple connections where different diameter fibers can be used in the channel.

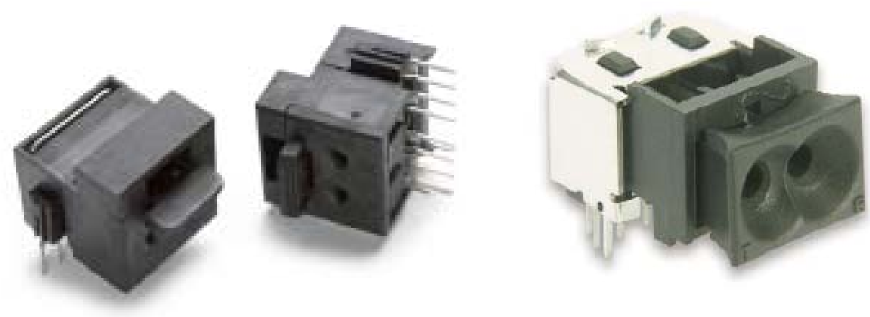


Figure 2 Connector-less Transceivers

Whether or not connectors are used, the decision to polish is optional with the POF technology. There are several cutters on the market that produce a reasonable cut to the fiber end whereby polishing is not necessary. If channel optimization is needed for length, then polishing is recommended. I will discuss the merits of polishing later in the paper. A study was performed to determine the various losses of fiber ends when prepared using different tools. Figure 3 shows various fiber cutting tools used to prepare the fiber ends.

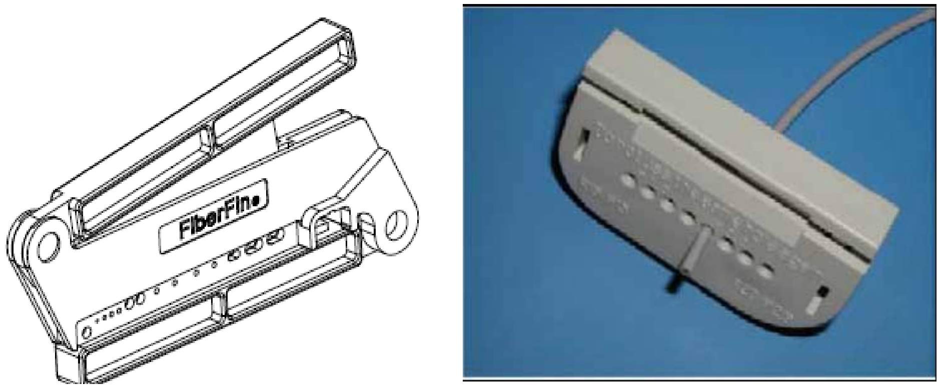


Figure 3 POF Cutting and Stripping Tools

In this test four different cutting tools were evaluated, side cutters, guillotine (razor blade) see figure 3, scissors and a combination cutter/crimper as shown in figure 1, Scissors and side cutters (not shown). Scissors and side cutters are normally only used for intermediate fiber preparation. The study concluded that the scissors and the side cutters produced a high loss connection that was in the 4dB per connection range. The Guillotine and combination cutter/crimper produced the best results of under 1.2dB.
The high loss connection produced by the scissors and side cutters was partially due to the small lateral fractures of the fiber during the cutting process.

Figure 4 Fiber End (edge cutter)

The guillotine cutters, using a special razor blade produce a smooth cut that is required for efficient light coupling.

Figure 5 Fiber End (guillotine cutter)

Polishing reduces the insertion loss of the fiber segment by increasing the light coupling efficiency (increases return loss) of the connection.

In general a properly polished fiber end will produce a connection on par with glass fiber connectors. When polished with clean 0.3 micron film, the connection will have a very low insertion loss. Figure 6 shows a fiber end that was improperly polished with a used 600 grit polishing paper. This connection produced a insertion loss of about 2.2dB per connection. Note this is a 1 dB increase in insertion loss from the guillotine cutter.

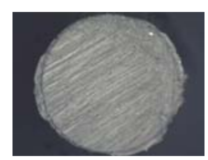


Figure 6 Poorly polished fiber

When a clean 0.3 micron lapping paper is used insertion loss will decrease to a typical 0.7dB per connection. The surface will exhibit a mirror like finish as shown in figure 7.

Figure 7 Fiber polished 0.3 micron paper

The result of over polishing is non-reversible. Over polishing will cut the fiber back to far resulting in a significant gap between the two fiber ends when coupled. If the scratches are below the fiber connector

ferrule additional polishing will be very difficult because the ferrule will prevent the polishing paper from reaching the deep scratches below the end of the fiber.

Table xx summarized the insertion loss for a number of fiber end preparation techniques studied.

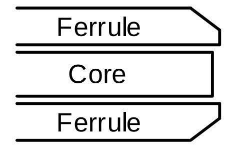
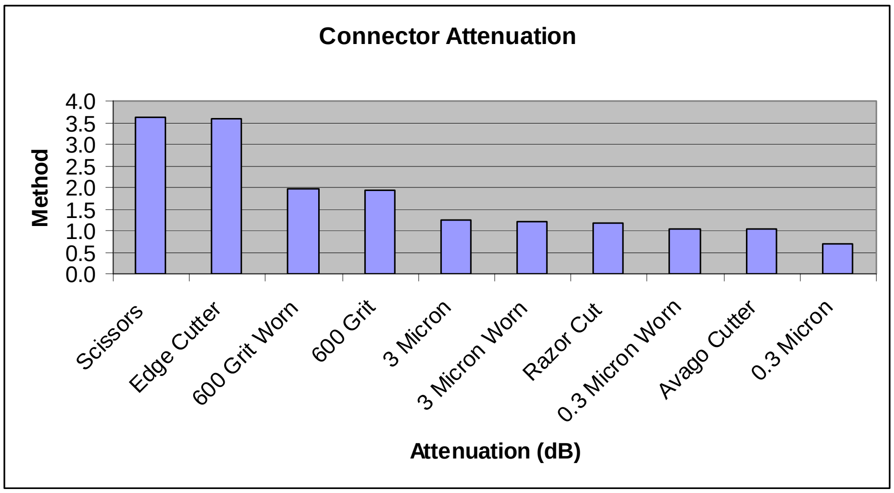


Figure 8 Fiber setback

Table 1 Summary of connector insertion losses with various cable preparation techniques.



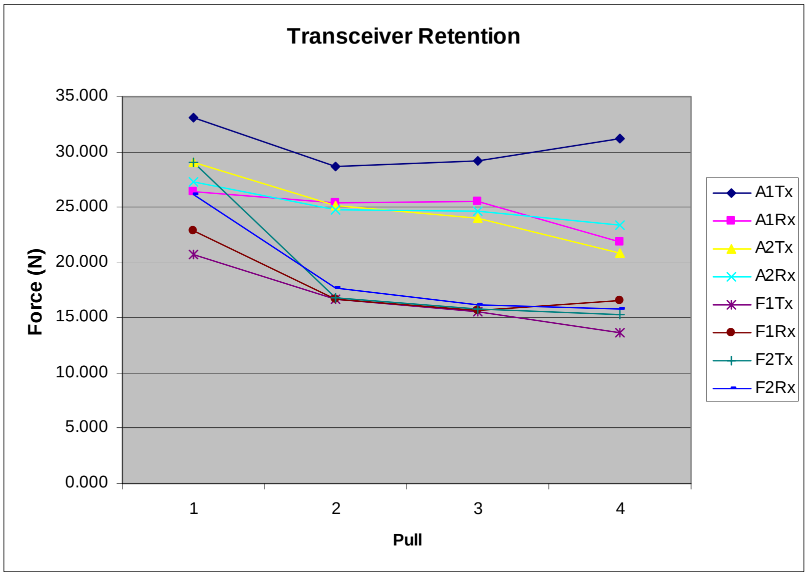
Temperature and Humidity

Temperature and humidity can have adverse effects on POF. Preliminary findings indicate that there is an impact to the fibers attenuation when subjected to long term temperature and humidity. The fiber was tested over temperature and humidity with connector-less transceivers. It was found that there is no significant increase in insertion loss to the fibers when subjected to temperatures at or below 75 Degrees C and 95% humidity. Further it was found that the fiber test length attenuation increased by 6 dB when subjected to 85 Degrees C at 95% humidity. This is 10 degrees over maximum allowed by specification. The increase in attenuation was permanent and does not appear to be cumulative for repeated exposures.

Retention forces of connector-less transceivers.

The study focused on two major but different fiber optic transceivers. The retention forces were measured over 4 successive pulls of the fiber from the transceiver. The study concluded that the initial retention force is manufacture dependant and ranged from 25000 newtons to 35,000 newtons. After 4 pulls the retention degraded by about 30% of the initial value. Table xx below shows the degradation of retention of several connections.

Table 2 Connection retention over forced pulls



Even though the retention decreased over repeated pulls, the retention of the fibers within the transceiver is still adequate for industrial applications.

Conclusion:

POF technology has progressed over the past several years though adoption and expansion into the automobile applications. These areas are harsh environmental areas where robust components are necessary for reliability. This media provides a natural solution for some harsh environments in the industrial areas. When applied as a 100Base-FX network the max channel length reduces from 100m to 55m. The total cost of ownership using this media over other fiber media,s is factors less. This media can be installed and terminated with little or no training using ordinary tools and little or no fiber polishing. Other fiber optic systems such as glass type systems require connectors, POF does not. Today connectivity is generally IP20 for POF systems. This is not the case in the near future. There is work in process where new IP 67 connector systems will emerge for use in POF systems.