Design and Development of a Mux/Demux Element for WDM over POF

M. Haupt, U.H. P. Fischer
Harz University of Applied Sciences, Friedrichstr. 57, 38855 Wernigerode, Germany
mhaupt@hs-harz.de

***Abstract* - POFs (polymer optical fibers) replace traditional communication media such as copper and glass step by step within short distance communication systems, mostly because of their cost-effectiveness and easy handling.**

POFs are used in various fields of optical communication, e.g. the automotive sector or in-house communication. The current "state of the art" are single mode communication systems. These systems use only one wavelength for communication, which limits the bandwidth. For future scenarios, this traditional technology is the bottleneck of bandwidth, e.g. for HDTV with IP-TV.

One solution to surpass this limitation is to use more than one wavelength over one single fiber, a technique known as WDM (wavelength division multiplexing). This multiplexing technology requires two more technical key-elements: a multiplexer, which combines the multi-wavelengths signals into one fiber and a demultiplexer at the end of the network to separate the colored signals.

This paper will show computer simulation of the design of several demux/mux-element patterns. The main idea is to split and combine the different wavelengths by means of a grating on an aspheric mirror. The following realization of this key element will be done with injection molding. This technology offers easy and very economical processing. These advantages make this technology first choice for optical components in the low-cost array.

I. Introduction

Polymer Optical Fibers offer many advantages compared to alternate data communication solutions such as glass fibers, copper cables and wireless communication systems.

In comparison with glass fibers, POF offer easy and cost-efficient processing and are more flexible for plug interconnections. POF can be passed with smaller radius of curvature and without any disruption because of larger diameter in comparison with glass fiber.

The clear advantage of using glass fibers is their low attenuation, which is below 0,5db/km in the infrared range. In comparison, POF can only provide acceptable attenuation in the visible spectrum from 350nm up to 750nm, see fig. 1 and 2. The attenuation has its minimum with about 85db/km at approximately 570nm. For this reason, POF can only be efficiently used for short distance communication. The disadvantage of the larger core diameter is higher mode dispersion.

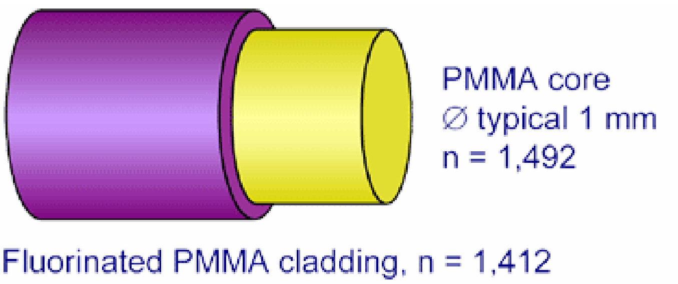

Fig. 1 Scheme of a standard POF.

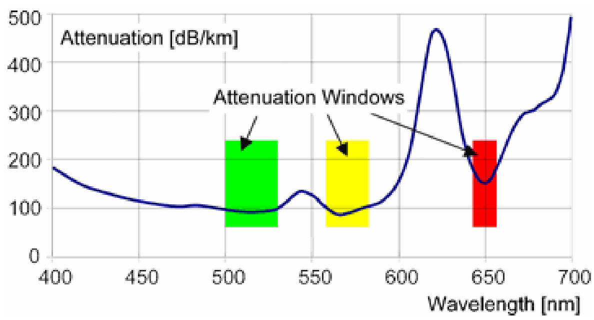

Fig. 2 Attenuation of a standard POF.

The use of copper as communication medium is technically outdated, but still the standard for short distance communication. In comparison, POF offers lower weight and space. Another reason is the nonexistent susceptibility to any kind of electromagnetic interference [1-3].

Wireless communication is afflicted with two main disadvantages. The electromagnetic fields can disturb each other and probably other electronic devices. Additionally, wireless communication technologies provide almost no safeguards against unwarranted eavesdropping by third parties, which makes this technology unsuitable for the secure transmission of volatile and sensitive business information.

For these reasons, POFs are already applied in various applications sectors. Two of these fields are described in more detail: the automotive sector and the in house communication sector.

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A. POF in the automotive sector

POF displaces copper in the passenger compartment for multimedia applications. It was first introduced by BMW in the 7er series in 2001. Since then not only high class cars were equipped with POF, even volume cars benefit of the advantages of POF [4, 5].

The exchange of the communication medium leads to lower weight. For example, in the Mercedes S-Class the weight was reduced by about 50kg due to the exchange of the transmission medium used.

The glass temperature of POF (below 100°C) makes using the fiber in the engine compartment impossible [4], although this problem might be solved in the foreseeable future. Another application in the car, where POF most likely will be used in the future, is as sensors for measuring various in-car pressures or forces.

B. POF in the in house communication sector

Another sector where POF displaces the traditional communication medium is in-house communication [6, 7], although the possibilities of application are not confined to the inside of the house itself. In the future, POF will most likely displace copper cables for the so-called last mile between the last distribution box of the telecommunication company and the end-consumer. Today, copper cables are the most significant bottleneck for high-speed internet.

“Triple Play”, the combination of VoIP, IPTV and the classical internet, is being introduced to the market with force, therefore high-speed connections are essential. It is highly expensive to realize any VDSL system using copper components, thus the future will be FTTH.

As mentioned before, POF can be applied in the house itself for different scenarios:

- “A/V Server Network” (communication between e.g. television, HiFi-receiver and DVD-player)
- “Control Server Network” (messaging between e.g. door lock and lightning system)
- “Data Server Network” (data exchange between e.g. notebook and printer)

These different application layers are further illustrated in fig. 3.

C. The Motivation for WDM over POF

Within the preceding paragraphs, several sectors where introduced, where POF offers advantages when compared to the established technologies. Other possible industrial sectors include the aerospace or the medical sector. All these applications have one thing in common – they all need high-speed communications systems.

The standard communication over POF uses only one single channel [1,2]. To increase bandwidth for this technology the only possibility is to increase the data rate, which lowers the signal-to-noise ratio and therefore can only be improved in small limitations.

This paper presents a possibility to open up this bottleneck. In glass fiber technology, the use of the WDM (wavelength division multiplexing) in the infrared range at about 1550nm has long been established [8-10]. This multiplexing technology uses multiple wavelengths to carry information over a single fiber [11]. This basic concept can – in theory – also be assigned to POF. However POF shows different attenuation behavior, see fig. 1. For this reason, only the visible spectrum can be applied when using POF for communication.

For WDM, two key-elements are indispensable: a multiplexer and a demultiplexer. The multiplexer is placed before the single fiber to integrate every wavelength to a single waveguide. The second element, the demultiplexer, is placed behind the fiber to regain every discrete wavelength. Therefore, the polychromatic light must be split in its monochromatic parts to regain the information. These two components are well known for infrared telecom systems, but must be redeveloped for POF, because of the different transmission windows.

One technical solution for this problem is available [12], but it cannot be efficiently utilized in the POF application scenario described here, mostly because this solution is afflicted with high costs and therefore not applicable for any mass production.

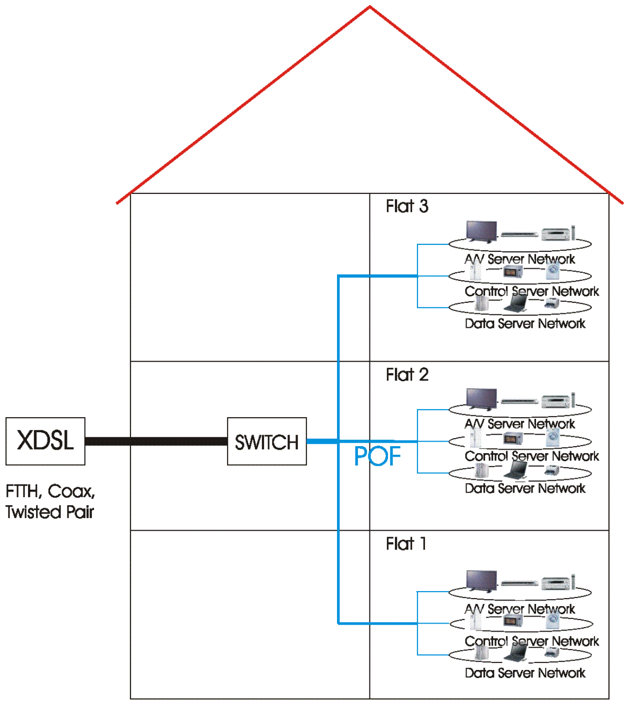


Fig. 3 In house Communication with POF.

II. Basic Concept of the Demultiplexer

As mentioned before, a demultiplexer is essential for WDM. Several preconditions must be fulfilled to create a functional demultiplexer for POF. First of all, the divergent light beam, which escapes the POF, must be focused. This is done by an on-axis mirror. In the first attempt, a spherical mirror is used. To get perfect results without any spherical aberrations, an ellipsoid mirror should be used.

The second function is the separation of the different transmitted wavelengths. In figure 4, this principle is illustrated for three wavelengths (red, green, blue). This is not a limitation for possible future developments, but rather an experimental basis from where to run the various simulations described below. The diffraction is done by a diffraction grating. The diffraction is split into different orders of diffraction. The first order is the important one to regain all information. There a detector line can be installed to detect the signals.

Because the grating is attached to a bended basement only one element can cover both functions, the focusing and the diffracting. Hence the light is not afflicted with any aberrations or attenuations of a focusing lens or other refractive elements, which are necessary for any other setup [13].

One other characteristic of key elements for POF communication is the three dimensional approach. Key elements of glass fiber communication are usually designed planar. This simplification cannot be adopted for POF communication, because of the large Numerical Aperture and therefore large opening angle of the POF.

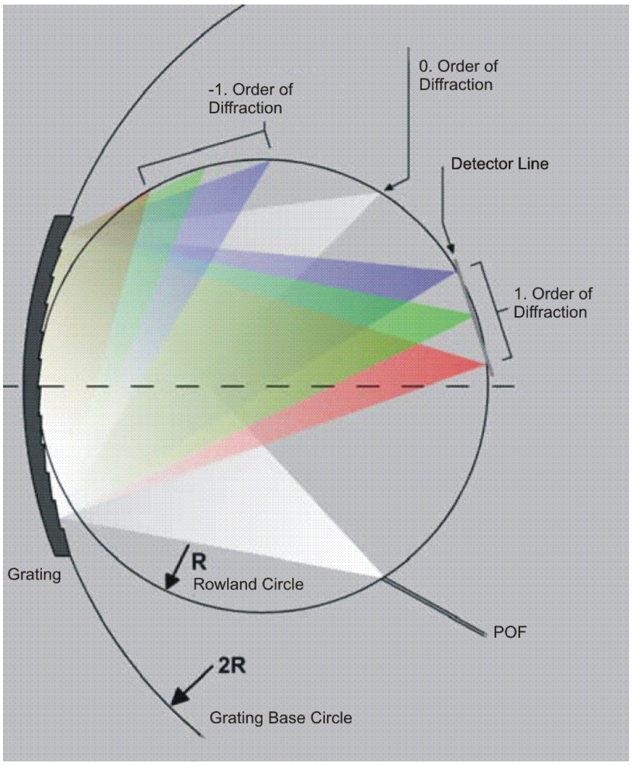


Fig. 4 Principle sketch of a Rowland Spectrometer [based on 14].

III. Results of the Simulation

In the following steps, a software program is used to design a demultiplexer based on the general concept outlined above. For the current task, the software OpTaLiX provides all needed functionalities [15]. This approach offers different advantages, it is easy to design, analyze and evaluate the simulated results. Also, effective improvements of the configuration can be simulated fast.

A. Results of the Simulation for different line densities

In figure 5, the 2D plot for the reference wavelength (520nm) of the demultiplexer with an ellipsoid mirror and grating is shown. The multicolored light is emitted by a polymeric fiber. It hits the mirror, where it is focused and diffracted in its monochromatic parts. The light is focused onto a POF- or detector-array.

Without a grating, a perfect point to point mapping (without any aberrations) is possible with an ellipsoid mirror because of the two foci, but there is no separation of the different channels. With a grating stamped on the mirror, the separation of the multicolored light in its monochromatic parts is possible. But this grating distorts the optical path of light dramatically.

The first change is the gap of the different colors in the image layer (here the POF- or Detector Array) increases with the line density of the grating, see figure 6 and 7. This can be noticed for an ellipsoid mirror (figure 6) and for a spherical mirror (figure 7) as well. The spherical mirror has the advantage, that the shape can be produced for injection molding easier.

The second changes are the great aberrations especially for the demultiplexer high line density. To underline this result and to analyze the aberrations in detail, the transverse ray aberration (TRA) and the optical path difference (OPD) in spectrometer mode are shown in figures 8 and 9 for the demultiplexer with an ellipsoid mirror and 1200 lines/mm. The chief ray coordinates are irrespective for the TRA and OPD to overlap the different colors.

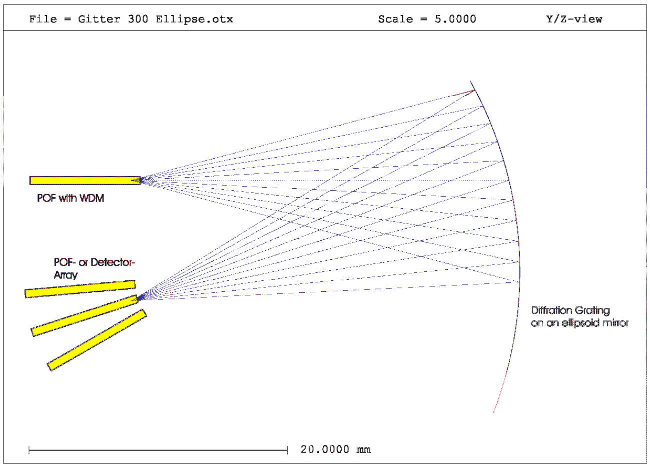
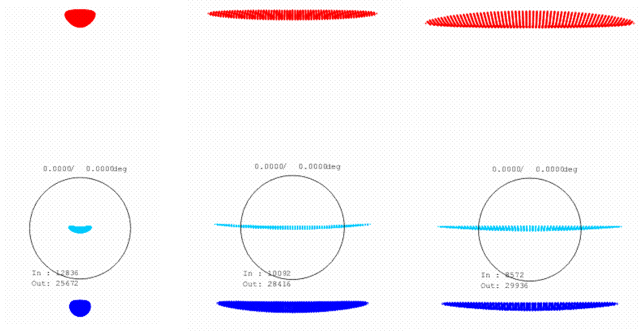


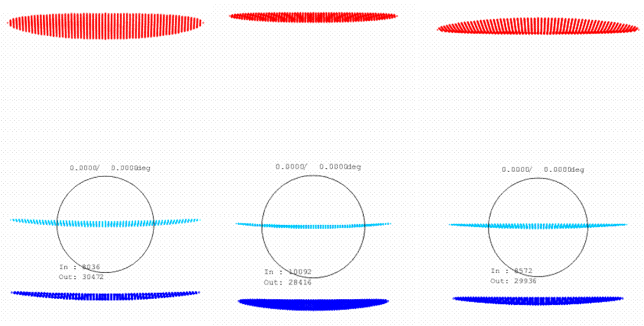
Fig. 5 2D plot of the demultiplexer.



300 Lines/mm 600 Lines/mm 1200 Lines/mm

Circle 0,5mm Circle 1,0mm Circle 2,0mm

Fig. 6 2D Plot of the demultiplexer with an ellipsoid mirror.



300 Lines/mm 600 Lines/mm 1200 Lines/mm

Circle 0,5mm Circle 1,0mm Circle 2,0mm

Fig. 7 2D Plot of the demultiplexer with a spherical mirror.

The TRA (fig. 8) shows a slight defocusing for the meridional section, but a very strong defocusing for the sagittal section. The graph of the function in the meridional section exhibits a predominant third order Seidel coefficient. Therefore the slight defocusing in the meridional section compensates the astigmatism. The OPD (fig. 9) shows as expected strong deviation from the ideal waveform especially in the sagittal section. This defocusing leads to high losses for the coupling efficiency for the POF- or detector- array in the image layer.

B. Results of the Simulation for the demultiplexer with improved mirror shape

It is obvious that the grating changes the focal length especially of the sagittal section; therefore the shape of the mirror must be improved. It is necessary to change the radius of curvature notable in the sagittal section. Hence the basic shape of the mirror is not longer a sphere or ellipsoid. To meet the demands a higher order shape, which is nearly cylindrical, is used.

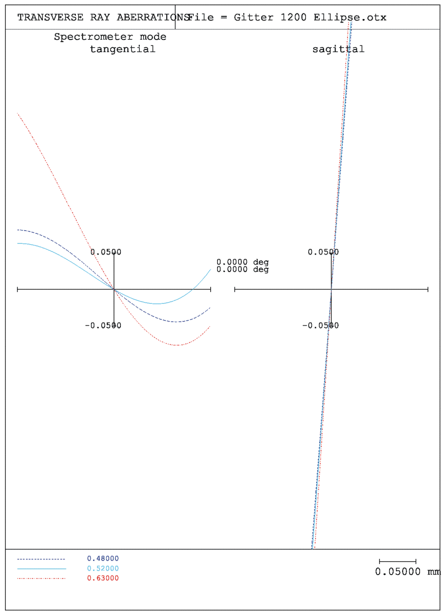


Fig. 8 TRA for the ellipsoid demultiplexer with 1200 lines/mm.

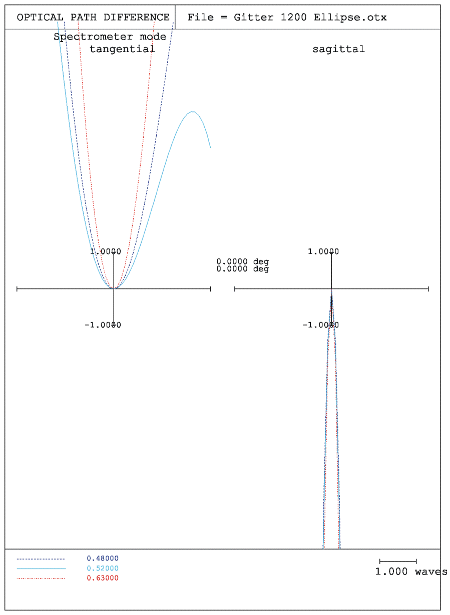


Fig. 9 OPD for the ellipsoid demultiplexer with 1200 lines/mm.

The change of the mirror shape improves the imaging quality substantial. The Spot Diagram and the TRA for the improved demultiplexer are shown in figure 10 and 11.

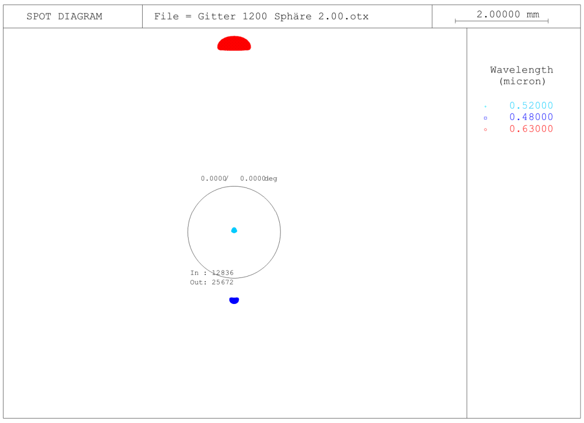


Fig. 10 Spot Diagram (circle diameter 2mm) for the improved demultiplexer.

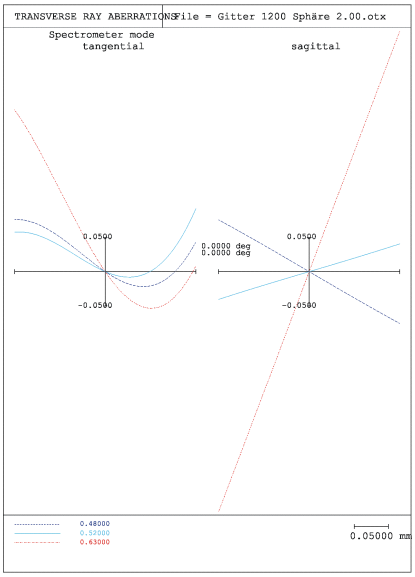


Fig. 11 TRA for the improved demultiplexer.

The Spot Diagram shows three dividable colors. The gap between every color is larger than 2mm. The TRA shows a marginal shift of the focus of all wavelengths to offset the astigmatism in the meridional section. Because of the spectrometric function of the demultiplexer it is not possible to focus all three colors simultaneously. There is always a combination of over and under correction for the different colors. Hence the radius of the mirror in the sagittal section is optimized to focus the colors in whole as much as possible.

This improved demultiplexer can separate three colors with enough space between them to regain the information with a POF- or detector-array. The shapes of the foci feature low coupling losses and the shape of the mirror should be easy to produce in injection molding.

IV. Conclusion

The Polymer Optical Fiber exhibits many advantages in comparison to glass fiber and copper as the medium for communication. The mentioned applications show different sectors where POF is already applied.

State of the art for POF communication is the use of only one single channel. This means a limitation of bandwidth. The solution for this bottleneck is WDM over POF, there not only one channel is used to transmit information over a single fiber. To use this technique two key elements have to be designed completely new: a multiplexer and a demultiplexer, because the key elements of the established WDM for glass fibers in the IR cannot be applied.

The simulation results show, that it is possible to build up a demultiplexer by means of a diffraction grating. A special shape of the mirror is needed to suppress most of the aberrations which results of the grating. The improved demultiplexer can separate all three colors with a gap of 2mm and crosstalk lower than 30dB. So in combination with injection molding this configuration can be produced with sufficiently costs. This demultiplexer has the chance to break through the limitation of standard POF communication.

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