Prism-Spectrometer as Demultiplexer for WDM over POF

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Abstract—*Polymer Optical Fibres (POFs) show clear advantages compared to copper and glass fibres (GOFs). In essence, POFs are inexpensive, space-saving and not susceptible to electromagnetic interference. Thus, the usage of POFs has become a reasonable alternative in short distance data communication. Today, POFs are used in a wide number of applications due to these specific advantages. These applications include automotive communication systems and In-House-Networking. The currently used transmission technology via POF is based only on one channel (or rather on one wavelength), making the usable bandwidth the limiting factor of this technology. One potential solution to expand the usable bandwidth of POF-based systems is wavelength division multiplexing (WDM). Because of the attenuation behaviour of POF, the only transmission window is situated in the visible spectrum. The solution proposed in this paper allows the transfer of several signals on different wavelengths through a single polymeric fibre. In order to separate the transmitted signals, special separators – called demultiplexers (DEMUX) – are utilized. These DEMUX are realized by employing the principle of the prism-spectrometer. In the set-up described in this paper, the light emitted by the polymeric fibre is collimated via an off-axis parabolic mirror. Then it is led to a dispersion prism and there divided into its monochromatic parts.*

Key words - *WDM, POF, demultiplexer*

1. Introduction

1.1 Advantages and Applications of POF

Polymer Optical Fibres offer essential advantages compared with GOF technology, copper cable and wireless communication. In comparison to GOFs, POFs show a greater mechanical flexibility making them uncomplicated in handling because of the smaller bend radius.

Also, polymer optical fibres can be stressed mechanically much stronger because of their geometrical dimensions. In comparison to copper cables, which are still standard in industry and technology, optical polymer fibres save more space and weight. They allow an easy connector assembly as well. Additionally, they cannot be influenced by electromagnetic fields [1-4]. The wireless data communication technology has two basic disadvantages compared to fiber technology. First of all, the electromagnetic fields can lead to interferences. Additionally, the radio technology is not secure from interference by third persons. As a result of the mentioned features, POFs offer an attractive alternative.

Nevertheless, POFs have only one transmission window, which is allocated in the visible spectrum of light. The attenuation of POF is too high for the remaining electromagnetic spectrum and therefore not acceptable for data transfer.

POFs are therefore best suited for the use in short distance data communication. Today, POFs are applied in in-house-networks and widely in the automotive industry [5]. It can thus be concluded, that POF technology is widely applicable.

1.2 WDM over POF

The transmission with standard POF is realised with only one wavelength [1-2]. The only possibility to increase the bandwidth is to raise the data rate. This reduces the signal-to-noise-ratio and can be changed therefore only in strong limitations. In this paper, an established technique for GOF technology is introduced and applied for POF. Though, it concerns the wavelength multiplex technology. There are different multiplex technologies available, e.g. time division multiplex (TDM) [6]. Recently WDM (wavelength division multiplex) and code division multiplex (CDM) have been used in GOF-infrared systems and in mobile RF communication [7-10]. The principle of WDM is transferred to the visible spectrum for POF communication, which means several wavelengths are used which are transmitted at the same time over one fibre. For more than 15 years, WDM widely expanded the overall transmission bit rate in GOF-long-range systems, because of its easy expandable system approach: adding one new source with different transmission wavelength in combination with a MUX/DEMUX-element expands the usable transmission rate directly by this source. Due to the attenuation of POF, the wavelengths from 400nm to 700nm [1] are used for the WDM, as shown in fig. 1.

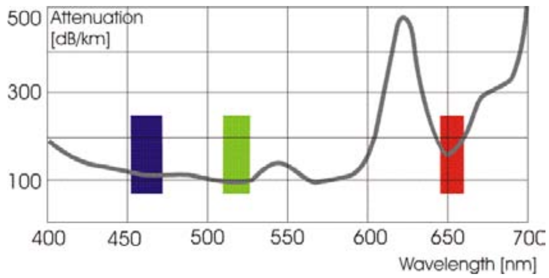

Fig. 1 Attenuation behaviour of a POF in the area of the visible spectrum

For the use of WDM technology in POF-systems, the same key elements are needed: the multiplexer and the demultiplexer. A complete redesign of these components is necessary, because a different spectrum is used. The light has to be combined by the multiplexer and split by means of a demultiplexer. This can be realised by means of different techniques. An optical phased array can be applied to change the phases of every different channel and therefore to divide the light in different channels [11]. Another possible technique are interference filters, which are well-known in the infrared range but also available for the visible spectrum [1, 12]. But key elements which are already available on the market use the infrared wavelength range or are cost-intensive solutions and thereby not suitable for mass market POF applications.

2. BASIC CONCEPT OF THE MULTIPLEXER

For WDM over POF, a complete new-developed demultiplexer is required, as described in the previous chapter. The principle of the demultiplexer is schematically illustrated in fig. 2 and is already pending patent [13-15].

A standard SI-POF with a core diameter of 980µm and a cladding thickness of 10µm is used. The refractive index of the core is about the whole cross section equal 1.49 and the numerical aperture is 0.5.

The light emitted from the POF is focused and divided by the DEMUX. The POF is situated in the focus point of an off-axis parabolic mirror on which the light is reflected. To reduce the aberrations of the dispersion prism, the beams of light are leaded collimated. The prism separates the light in its different wavelengths. At the end of the DEMUX, a plano-convex lens focuses the separated wavelengths onto a detection layer.

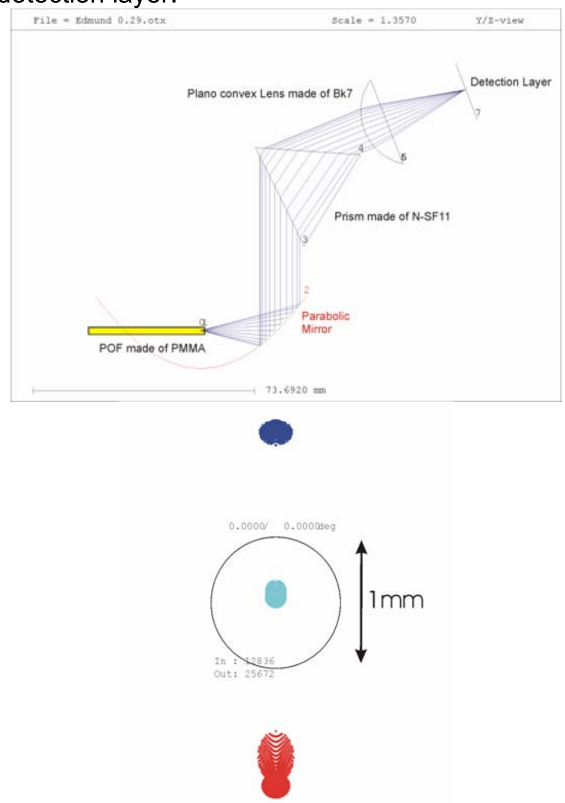

Fig. 2 Setup of the demultiplexer and the focus points at the detection layer in the simulation

The setup uses only three colours, blue (480nm), green (530nm) and red (660nm). This is not a limitation for possible future developments, but rather an experimental basis to run the various simulations described below.

3. SIMULATION AND RESULTS OF THE SIMULATION

In the following step, a simulation 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 [16]. 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. The simulated design was planned and developed with available standard components.

In the simulation of the DEMUX, all three colours are detectable on the image layer, as shown in fig. 2. The different focus points show a diameter lower than 1mm. The cross talk is below -30dB, because at the detection layer the different channels do not overlap each other.

4. LAB SETUP OF THE POF-DEMUX

4.1 Assembly

To verify the simulation results, the DEMUX is realised with commercially available standard components under lab conditions. The components are chosen, because they are inexpensive and the geometrical dimensions are close to the optimal design [17]. The complete construction is shown in fig. 3.

The various optical components effect the size of the focus point in the image layer differently. Especially the positioning of the POF and the off-axis parabolic mirror have to be assembled precisely, because a divergence of a few micrometers in any direction affects the focus size considerably at the detection layer. So for both of these optical elements, micrometer stages are used to guarantee a precise adjustment.

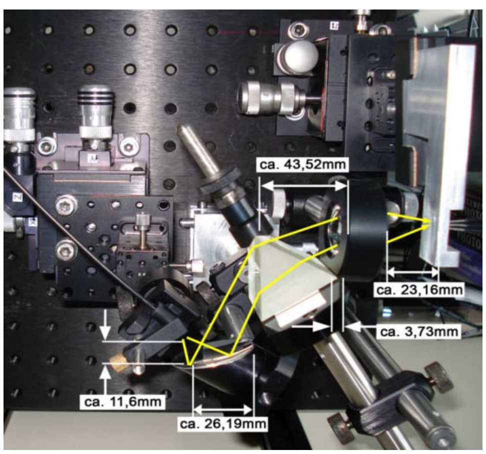

Fig. 3 Lab setup including the path of rays

A separation without viewable overlap of the three channels is achieved with an optimal alignment of the optical elements and a concurrent transfer of the wavelengths over POF used for this lab setup. The intensity dispersion is shown in fig. 4. It is demonstrated, that a clear separation of the different channels is achieved. However, the spectral width of the different channels avoids a clear determination.

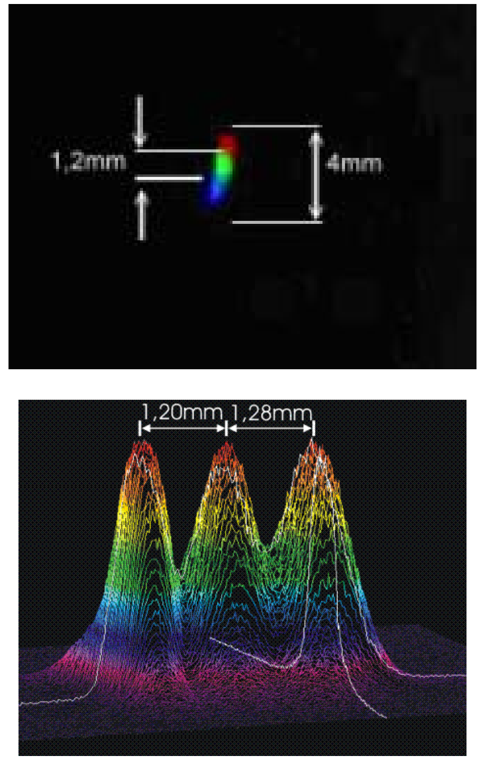

Fig. 4 Detection layer of the lab setup and measured intensity of the focus points

4.2 Characterisation of the DEMUX-Setup

In the first step, a characterisation of the lab setup is demonstrated for the attenuation behaviour and channel bandwidth. For the measurement of the general attenuation of the DEMUX, the colours blue, green and red will be transferred without multiplexing. For the channels blue and red media converters from DieMount [18] and for the green channel the OPTOTEACH teaching system of HarzOptics [19] are used.

Furthermore, a white light source (YOKOGAWA AQ 4305) is used for the estimation of the available bandwidth for every channel, see fig. 5.

Fig. 5 Schematic setup with white light source

A connection is built up with all three WDM-channels (470nm, 520nm, 650nm), see fig 6.

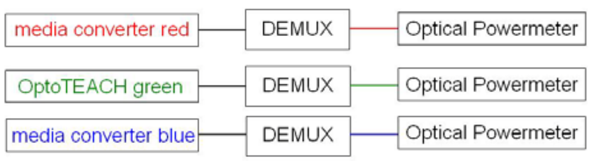

Fig. 6 Schematic setup for 3 channel attenuation measurement

The attenuation caused through the data transfer by the system is at blue 19,3dB, at green 12,1dB and at red 14dB. A coupler of the company HarzOptics for the combination of two channels causes an additional attenuation of about 5-6dB, see table 1. Fig. 7 demonstrates the existing cross talk of the different channels.

By means of a white light source, the spectrum is measured to verify the received signals and to estimate the channel bandwidth, as shown in fig. 7. The cross talk between the blue channel and the green channel is 4,6dB respectively 16,1dB. Also, the cross talk of the green channel to the red channel is rather high with 13,3dB. It can be recognised, that the spectral width of the red channel is larger in comparison to the blue channel. An explanation can be found in fig. 8, the steeper the curve falls the larger the gap between the colours.

Optical component \ Channel	λ = 470nm	λ = 520nm	λ = 650nm
Attenuation DEMUX (1 channel) [dB]	19,3	12,1	14
Attenuation DEMUX (with coupler & connector) [dB]	23,9	18,9	19,8

TABLE 1. ATTENUATION RESULTS OF THE DEMULTIPLEXER

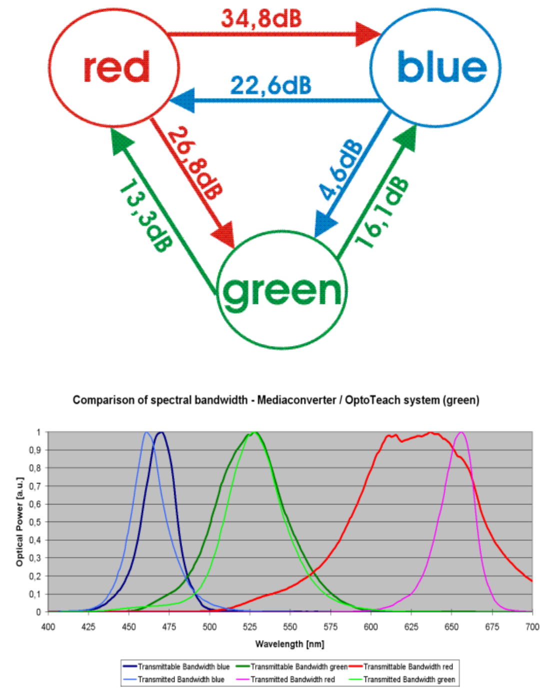

Fig. 7 Cross-talk of the 3 channels and comparison of the spectra

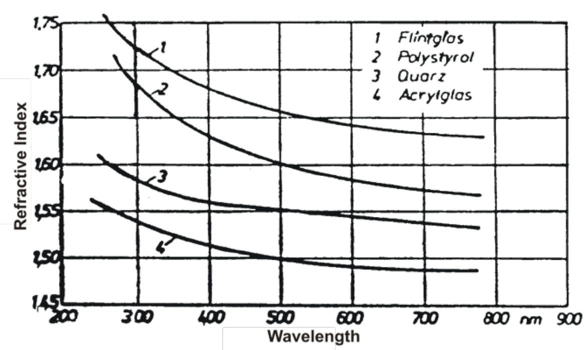

Fig. 8 Refractive index in dependence of wavelength

Therefore, the dispersion of the prism is non-linear. Furthermore the attenuation trait is also to view for short POF-lengths. This can be seen in the curve progression of the red channel. It shows an easy reduction of the signal power located for the wavelength area about 620nm, shown in fig. 1.

4.3 Data Transfer

The first Fast Ethernet data transfer was designed and tested with the colours red and blue, see fig. 9. An error-free transfer of data was realised. For the Ethernet data transfer the DEMUX behaves transparent. The functionality of the WDM-system is thus verified.

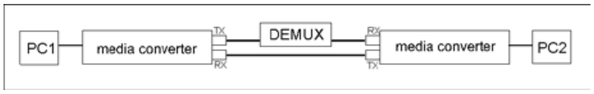

Fig. 9 Schematic setup Ethernet data link

However, because of the attenuation, which is still too high, the data transfer is possible with only one channel. For a data transfer via WDM, the transmitted signals are too weak considering their appearing attenuation. With the media converters used in combination with couplers, a combined signal transfer is currently not possible, but it may become possible with a more precise adjustment of the focus length.

4.4 Conclusion and Outlook

This paper demonstrates, that it is principally possible to design and use a demultiplexer for polymer optical fibres and also to separate the different channels.

The adjustment of the optical components used in the lab setup exhibits a very high attenuation of the transmission link.

At the moment, it is only possible to transmit signals with high optical power to receive and use the transmitted signals with sufficient optical power at the end of the transfer distance, because of the high appearing attenuation. The focused signals at the detection layer are separated clearly as such and are detectable in comparison to the simulated spot diagram.

We still believe, that WDM over POF has a good potential to substitute the classical transfer technology in many areas of the short distance communication. But it is necessary to manufacture special components for this setup to increase the gaps between the channels. With standard components, an online three channel data communication assembly was not possible.

To make the WDM over POF solution attractive for the mass market, a possible inexpensive production must be implemented with improved components. One possible solution would be the moulding technology, which is a low-cost production with high amount of pieces.

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