Angular Mode Group Diversity Multiplexing for Multi-channel Communication in a Single Step-Index Plastic Optical Fibre

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The principle of Angular Multiplexing to realise independent communication channels in a relatively short step-index plastic optical fibre is described. This concept of Mode Group Diversity Multiplexing is based on the principle that the axial angle of light propagating in a step index multimode fibre is preserved over relative short distances. By using an array of lasers each launching light into the fibre at different axial angles and by detecting the light of different angle areas by an array of photo detectors at the receiver side, independent transmission channels are created in a single step index fibre. Moreover, these individual channels will have a higher bandwidth because each channel uses fewer modes. First experiments with 25 m step index plastic fibre with a diameter of 1 mm already show the feasibility of this principle. With Angular Mode Group Diversity Multiplexing in step index plastic fibre high capacity, transparent, low-cost, easy-to-install in-house multimedia networks can be realised.

Introduction

In-house, there presently is a wide variety of networks, each optimised for transporting a particular set of services (such as CATV, voice telephony, high-speed data, etc.). The lack of a common network infrastructure hampers the introduction of new services, and the creation of mutual relations between the services. Optical fibre may open the way towards such a common network. Optical fibre is not susceptible to electromagnetic interference, has no electromagnetic emission and does not conduct electricity so it can be installed in existing conduits used for mains power supply. This makes optical fibre from an installation point of view very attractive compared with copper coaxial and UTP cable. In particular, multimode fibre is attractive because it is easy to install due to its large core diameter, and it is already widely accepted for short-range data communications in broadband LANs, benefiting from low-cost transceiver modules [1]. Moreover, multimode Plastic or Polymer Optical Fibre (POF) offers large flexibility and ductility, which further reduces installation costs in often less accessible customer locations [2]. The large diameter of plastic fibre allows relaxation of connector tolerances without sacrificing optical coupling efficiency. This simplifies the connector design and permits the use of plastic injection-molded components. Step Index PMMA (Polymethyl-methacrylate) plastic fibre with a core diameter of nearly 1 mm has already been included into standards (Fire-Wire, MOST, etc.). However, in comparison to standard single-mode silica fibre, POF has per unit of length a lower bandwidth due to its higher dispersion caused by its multimode wave guiding behaviour. With Angular Multiplexing, which is a specific variant of Mode Group Diversity Multiplexing [3], we take advantage of this guiding behaviour. With Angular Multiplexing [4] individual transmission channels are created in a single step index fibre using individual mode groups. Because these individual channels use fewer modes, each channel will have less modal dispersion and thus a higher bandwidth compared with the bandwidth of the fibre using all modes. So with Angular Mode Group Diversity Multiplexing the transmission capacity of a single fibre is increased by creating multiple independent channels each with a higher bandwidth. These individual channels can be used for individual services in the customers premises. Its functionality is similar to wavelength multiplexing, but relatively expensive wavelength-selective devices are not needed; these can be replaced by lower-cost non-wavelength-specific devices operating in parallel.

Angular Multiplexing

Angular Mode Group Diversity Multiplexing is based on the principle that the axial angle of light propagating in a step index multimode fibre is preserved over several tens of meters. When a laser beam is coupled into the fibre under an angle smaller than the critical angle of the fibre, at a certain distance from the other end of the fibre a ring shaped pattern will appear, see Fig. 1. This effect arises because of the reflections of the light rays onto the circular core-cladding interface in the step index fibre. These ring shaped patterns are already observed after 1 meter of plastic fibre. The angle of the incidence beam θ_{in} is equal to the angle of the outgoing cone θ_{out} because the angle of the propagating light will be preserved even when the fibre is bent. The thickness of the ring shaped pattern depends, among other things, on the thickness of the core of the fibre and the numerical aperture of the incident beam.

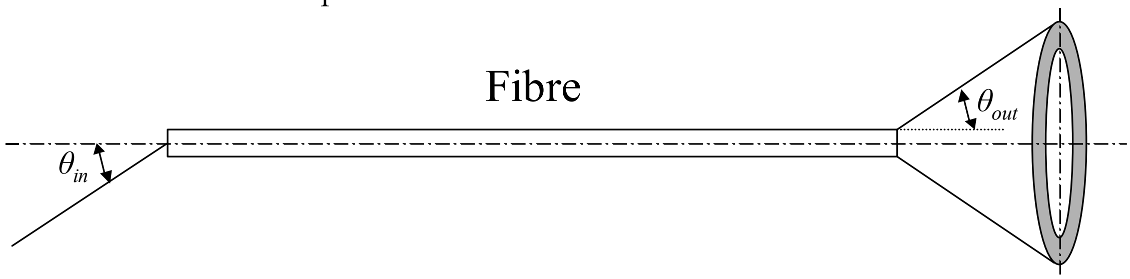


Fig. 1 Principle of Angular Multiplexing

By using an array of lasers each launching light into the fibre at different axial angles at the transmitter side and by detecting the light form different angular areas by an array of photo detectors at the receiver side, independent and separate transmission channels can be realized, see Fig. 2.

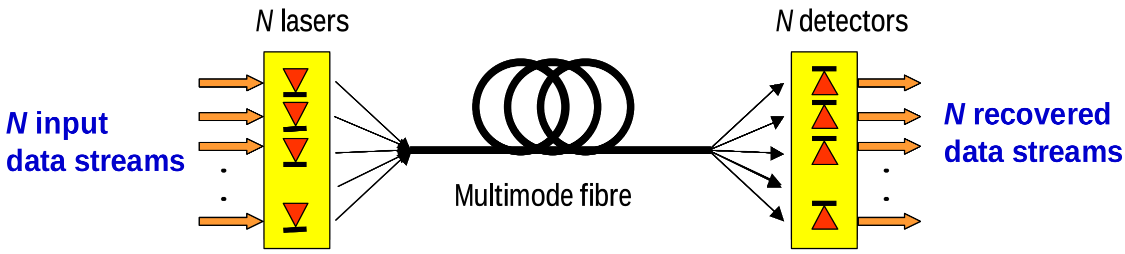


Fig. 2 Angular Multiplexing

Because of the relatively large core diameter of the plastic fibre, it is easy to couple light from different lasers under different angles into the plastic fibre. At the receiving end, some more optical components are needed to separate and focus the ring shapes onto photodiodes with a relatively small active area. In Fig. 3 a detection principle is shown using two lenses and ring shaped mirrors. For simplicity two channels are chosen. At the output end of the plastic fibre, a lens collects the light out of the fibre to form collimated beams. Behind this lens annular concentric mirrors are placed which deflect the light of a given ring by a specific angle. Via a second lens the light of the different channels is focused on an array of photodiodes.

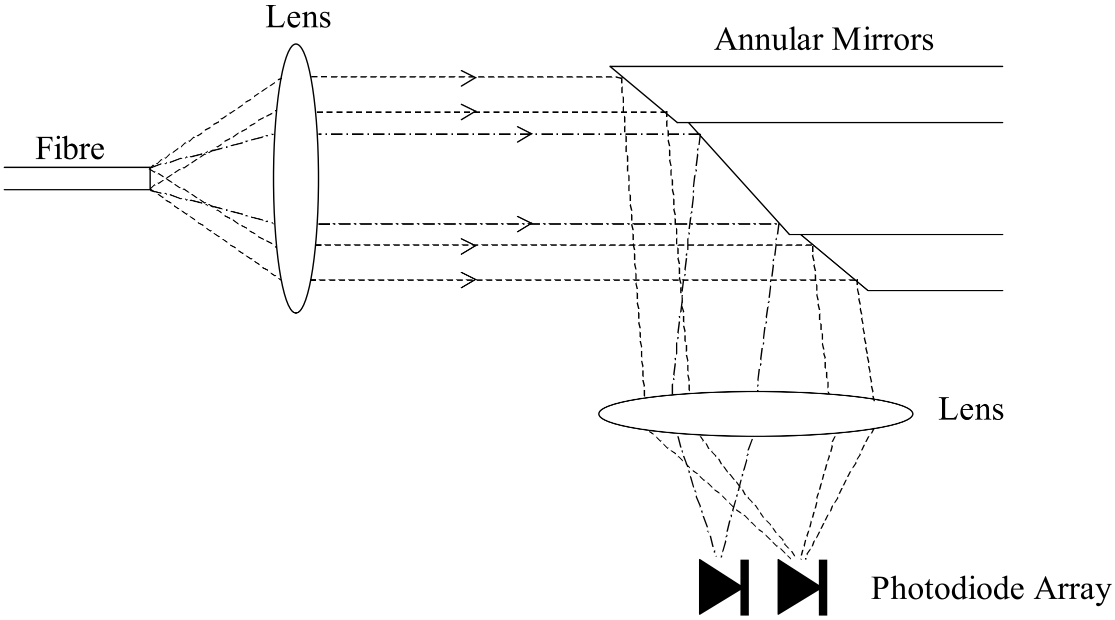
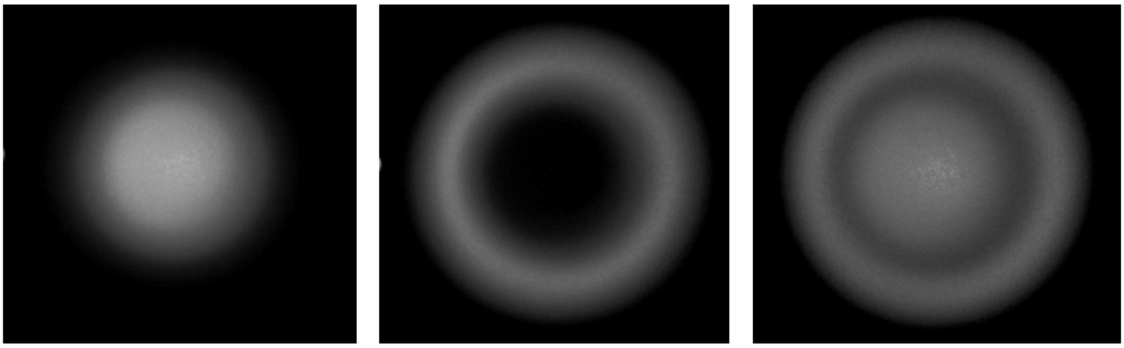


Fig. 3 Separation and detection of ring shaped patterns

Experimental Results

To demonstrate the applicability of Angular Mode Group Diversity Multiplexing, the goal of a first experiment is to show that two channels can be realised in a single step index POF. For this experiment we used a PMMA step index POF with a length of 25 m and with a core diameter of 980 µm and a cladding diameter of 1000 µm because this type of step index POF is already used in various POF system standards. The fibre has a Numerical Aperture of 0.5, which means that the critical angle under which light rays can be coupled into the fibre is 30 degrees. Although cheaper solutions are possible, two single mode pigtailed 650 nm lasers were used at the transmitter side. To minimise cross-talk between both channels, the light out of one pigtail is coupled in the direction parallel with the axial direction of the plastic fibre, and the other pigtail is coupled under an angle of 20 degrees to the axial direction. Because tolerances are very relaxed, a Plexiglas block with grooves is used in which the laser pigtails and the plastic fibre are fixed at these angles. Fig. 4 shows photographs of ring patterns, which are observed on a screen about 4 centimetres from the end face of the plastic fibre. Photo a) shows the pattern when only the laser of the parallel channel is switched on, photo b) shows the ring shaped pattern from the 20 degree channel and photo c) shows the pattern when both lasers are switched on. So after 25 meters of plastic fibre we can still observe a clear separation of both channels, even when the plastic fibre is moved or bent.



a) b) c)

Fig. 4 Angular patterns at output of 25 m POF a) only parallel channel on, b) only 20 degree channel on, c) both channels on

On the basis of ray tracing simulations two annular concentric mirrors have been designed. Fig. 5 shows a photograph of the realized mirrors. The diameter of the inner mirror is 10 mm and of the outer mirror 20 mm. The difference in angles between the two concentric mirrors is 5 degrees. The setup, which is under construction, will be completed with lenses and photodiodes and transmission experiments will be carried out.

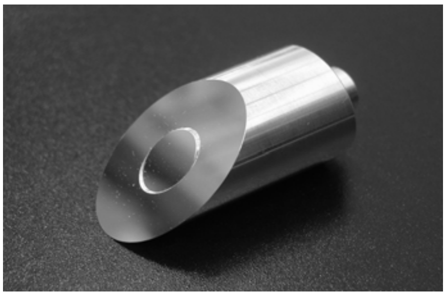


Fig. 5 Photograph of two annular concentric mirrors

Conclusions

With Angular Mode Group Diversity Multiplexing individual transmission channels with a higher bandwidth can be created in step index Plastic Optical Fibres using low cost non-wavelength specific optical components. These channels can be used for high capacity universal in-home multimedia networks.

References

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