The Effect of Passive Optical Components in Multimode Fibre Links Using Mode Group Diversity Multiplexing

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In short-reach multimode fibre (MMF) links, mode group diversity multiplexing (MGDM) can be used to create parallel, independent communication channels. Each channel uses a different subset of the propagating modes in the MMF. To allow for network topologies beyond the basic point-to-point scenario, passive components, such as optical splitters, are required. Such components may affect the modal spectrum of the MGDM channels and therefore the performance of the communication link. This paper presents an experimental investigation of the effect of passive optical components on an MGDM link.

Introduction

Multimode fibre (MMF) is extensively used in in-building and campus networks. Its large core diameter, in comparison to the single-mode fibre (SMF), facilitates its installation and handling. In MMFs, monochromatic light propagates in a multitude of modes. Each mode has a different spatial intensity distribution and propagation delay. Mode group diversity multiplexing (MGDM) is an intensity-modulation (IM), direct-detection (DD), multiple-input, multiple-output technique that uses groups of propagating modes to create independent, parallel communication channels. N lasers excite N different groups of modes and M detectors $(M \geq N)$ selectively respond to the optical power at the MMF output. The mixing among the channels is mitigated electronically [1, 2]. In short-reach networks, the effect of dispersion can be neglected when the bandwidth requirements are not very high. The transmission bandwidth can still be in the range of a few GHz for MMF links up to 100 m long [3]. In this case, the electrical output signals are related to the electrical input ones via a real-valued $M \times N$ transmission matrix $\mathbf{H}$. The matrix elements $h_{i,j}$ express the amount of optical power in the jth channel that is received by the ith detector.

MGDM requires mode-selective components to launch and detect the mode groups. Design considerations for graded-index (GI) MMFs have been presented [4], with radially offset beams at the GI-MMF input and a multi-segment detector with annular segments responding to the near field pattern (NFP) at the GI-MMF output. The intensity distribution of the NFPs of the MGDM channels determines the geometry of the detector. In particular, the areas of the detector's segments are chosen so as to minimize the crosstalk among the channels. In local area networks, bus, star and ring topologies are often deployed (Figure 1). To apply MGDM in such network topologies, passive optical components, such as optical couplers, are required. In this paper, we present an experimental investigation of the effect of several passive optical components on the NFP of GI-MMF links under selective excitation with an SMF.

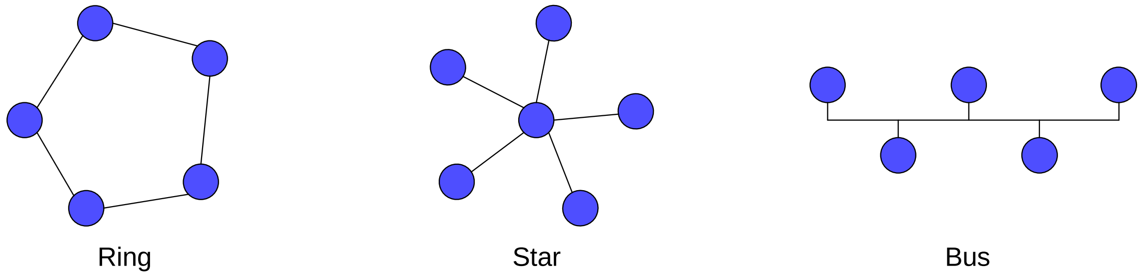

Figure 1: Common topologies in local area networks.

Experimental Results

The experimental investigation of the NFP was realized with the set-up illustrated in Figure 2. An external cavity type tunable semiconductor laser was used to selectively excite a 1 m long GI-MMF with core/cladding diameter of 50/125 μm and central numerical aperture (NA) 0.2. The wavelength of the laser was tuned at 1310 nm and its linewidth was 85 kHz. The laser was pigtailed with an SMF of 9.3 μm mode field diameter at 1310 nm wavelength. The SMF and GI-MMF axes were parallel and their lateral distance was set by computer-controlled translational stages. The axial distance between the SMF and the GI-MMF ends was in the order of a few microns to allow for the movement of the stages. The 1 m long GI-MMF was connected to a GI-MMF passive optical component followed by a 100 m long GI-MMF, both of the same type with the 1 m GI-MMF. The optical components were connected with FC/PC adapters. At the output of the 100 m long GI-MMF, the NFP was observed with an infrared vidicon camera and a microscope (magnification 50$\times$, NA 0.75). An image of the NFP was grabbed with video-processing software.

The intensity distribution of the NFP was observed when the radial offset of the SMF axis with respect to the GI-MMF one was 0, 12 and 21 μm, and for different passive optical components. The obtained NFP images are shown in Figure 3 for several cases, described in Table 1. A 2 m long GI-MMF, a monolithical 50/50 coupler, a monolithical 90/10 coupler and a 3-port circulator were tested. The couplers and the circulator are optimized for use at 1310 nm. When the 2 m long GI-MMF was tested (case 2), the overall shape of the NFP was very similar to the corresponding NFP at the output of the 1 m GI-MMF (case 1). This is meant to show the limited effect of the FC/PC adapters, present in every case. The NFP in 3, 4 and 5 appears to be nearly as in 1 and 2. In 7 and 8, the intensity distribution of the NFP for 0 μm radial offset at the input is slightly expanded, while for

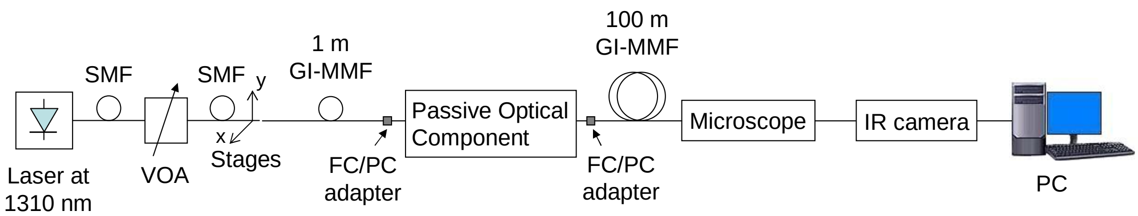

Figure 2: Experimental set-up for the investigation of the effect of passive optical components on the NFP of GI-MMF links.

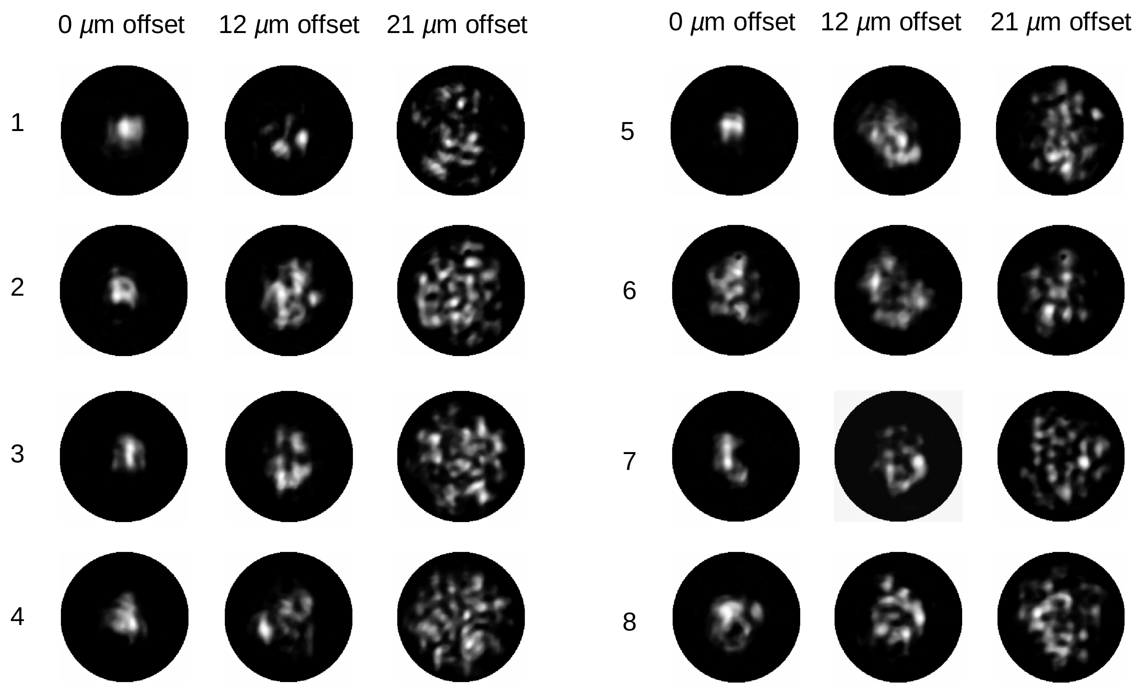

Figure 3: Intensity distribution of the NFP at the output facet of (1) the 1 m long GI-MMF (2-8) the 100 m long GI-MMF used in the set-up of Figure 2. The passive components used in 2-8 are described in Table 1.

the other two offsets it remains similar. Finally, in 6, the shape of the NFP seems to be independent of the offset of the input beam.

In order to use passive optical components in an MMF network with selective excitation, these components should not alter significantly the modal distribution and furthermore their specifications, such as the coupling ratio and the insertion loss, should be maintained. Apart from MGDM, this is of interest for the offset launch technique, which has been proposed to increase the bandwidth of IM-DD, single-input, single-output MMF links [5]. From the components we tested, only the circulator maintained its specifications for all offsets. The couplers did not exhibit a consistent coupling ratio, even though in several cases they did not change the overall shape of NFP.

Table 1: Description of the cases presented in Figure 3

Case	Passive component
2	2 m long 50/125 μm GI-MMF
3	monolithical 50/50 coupler, input 1 to output 1
4	monolithical 50/50 coupler, input 1 to output 2
5	monolithical 90/10 coupler, input 1 to output 1
6	monolithical 90/10 coupler, input 1 to tap 1
7	3-port circulator, port 1 to port 2
8	3-port circulator, port 2 to port 3

From the above investigation, standard MMF passive components do not seem to be suitable for MMF networks with techniques using selective excitation. Laser optimized components would be required [6]. The primary reason is that standard components, although in most cases they do not change dramatically the modal distribution, they do not respond according to their specifications. These specifications are usually given for overfilled launch conditions. This can be achieved with a source of high angular divergence, e.g. an LED, or a mode scrambler at the GI-MMF input [7].

Conclusions

We have presented an experimental investigation of the intensity distribution of the NFP at the output of a GI-MMF link comprising a 1 m long GI-MMF, a GI-MMF passive optical component and a 100 m long GI-MMF. We examined standard components, i.e. not ones designed for laser optimized operation. We have shown that in several cases the overall NFP remains similar with the NFP at the output of the 1 m GI-MMF. In some cases, the NFP is slightly affected when light is launched at the lower order modes at the input of the GI-MMF link. In most cases, though, these passive components did not seem to introduce a dramatic change in the mode distribution. This is very important for MGDM links. However, when MMF couplers were tested, the coupling ratio did not maintain its value according to the specifications. This hampers the use of such components in MMF networks with selective excitation.

Acknowledgment

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References

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