Tiering effect of solid-core photonic crystal fiber on controlled coupling into multimode fiber

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ABSTRACT

To enhance the channel impulse response and signal quality through a multimode fiber, the incident wavefront into a multimode fiber may be controlled using phase masks, gratings and spatial light modulators. In this paper, an elegant technique for controlled coupling into a multimode fiber is demonstrated using a solid-core photonic crystal fiber to reduce differential mode delay in a multimode fiber. The increase in the number of tiers of a solid-core photonic crystal fiber is shown to reduce differential mode delay and improve the bit-error rate of a multimode fiber channel.

Keywords: multimode fiber, controlled coupling, coupling efficiency, mode filter, differential mode delay, solid core photonic crystal fiber

1. INTRODUCTION

Multimode fiber backbones in Local Area Networks (LANs) are approaching their capacity limits due to the rapid bandwidth growth spurred by real-time triple-play services. To exceed the fundamental capacity limit of a multimode fiber, controlled coupling is viable for restricting the number of propagating modes in a multimode fiber, hence mitigating modal dispersion, the main source of signal loss in multimode fiber. The impulse response in controlled coupling into a multimode fiber may be customized by radial offsets (1-6), iterative optical equalization (7-12), holographic wavefronts (13-16), modal decomposition methods (17-19) and gratings (20, 21). A promising alternative for selective excitation in multimode fiber is by mode-filtering the incident wavefront using a solid-core photonic crystal fiber with a large numerical aperture and a modal profile localized to the center of the core.

This paper investigates the potential of solid-core photonic crystal fiber for controlled coupling in a multimode fiber. The performance of several refractive index designs of the solid-core photonic crystal fiber are evaluated in terms of modal decomposition, bit-error rate and differential mode delay at the multimode fiber output.

The remainder of the paper is structured as follows. Section 2 describes the proposed transmission model for controlled coupling using a solid-core photonic crystal fiber. Section 3 discusses the simulation results.

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2. CONTROLLED COUPLING INTO MMF USING SC-PCF

Figure 1 illustrates the transmission model for controlled coupling into a multimode fiber using a solid-core photonic crystal fiber, simulated in Optsim (22) and BeamPROP (23). The vertical cavity surface-emitting laser (VCSEL) emits a 2mW Gaussian beam polarized in the x-direction with a linewidth of 0.2nm. The VCSEL is driven by a pseudo-random binary sequence electrical signal. The transmission is based on non-return-to-zero (NRZ) coding at a bit rate of 40 Gbps. The output from a 15cm solid-core photonic crystal fiber is coupled into a 50µm/125µm graded-index multimode fiber with a refractive index profile parameter, $\alpha = 2.074$. The insertion loss between the multimode fiber and photonic crystal fiber is 1.5dB. Coupling between mode groups is modeled based on an iterative method (24). The length of the multimode fiber is varied from 200 meters to 1000 meters.

Three solid-core photonic crystal fiber waveguide structures were designed in BeamPROP - PCF A, PCF B and PCF C with four rings, five rings and seven rings respectively. The refractive indices of the core and holes are 1.45 and 1.00 respectively. The hole diameter is 2.5µm and the separation between two holes is 6µm. The ratio between hole separation and hole diameter is 2.4. The refractive index profiles of the solid-core photonic crystal fiber waveguides are presented in Figure 2. The transverse modal electric field from each solid-core photonic crystal fiber waveguide structure is computed using the iterative finite-difference beam propagation method to solve the scalar wave equation. The refractive index profile is assumed to be uniform along the z direction.

Figure 1. Mode-filtering by a solid-core photonic crystal fiber for controlled coupling into a multimode fiber

Figure 2. Refractive index profiles for (a) PCF A (b) PCF B (c) PCF C. The center core and surrounding material in red have a refractive index of 1.45; air holes in blue have a refractive index of 1.00.
3. SIMULATION RESULTS

As the Gaussian beam from the VCSEL propagates through the solid-core photonic crystal fiber, a significant amount of power is coupled into the LP01 mode of the multimode fiber whereas the remaining power is transferred to other modes of the multimode fiber, particularly LP11. PCF A, PCF B and PCF C achieve about 60%, 70% and 90% coupling efficiency respectively into LP01 at the end of the multimode fiber waveguide. To illustrate this, the resultant transverse electric fields from the modal decomposition into LP01 and LP11 of the multimode fiber for an incident wavefront from PCF C are given in Figure 3.

The differential mode delays for all solid-core photonic crystal fiber waveguides were analyzed. The pulse width for the original multimode fiber channel decreased with the introduction of any of the three photonic crystal fibers, with PCF C having the smallest pulse width, followed by PCF B and PCF A. For all photonic crystal fibers, the pulse width decreases slightly with increasing radial offsets. An example for PCF B is given in Figure 4.

![Figure 3. Decomposition of electric field output into LP01 and LP11 for PCF C. The color scale represents the variation of the normalized transverse electric field](image)

![Figure 4. Differential delay for various radial offsets from multimode fiber axis for PCF B at 400 meters](image)
Eye diagrams for the multimode fiber channel without any solid-core photonic crystal fiber and with the inclusion of three solid-core photonic crystal fibers at 400m are shown in Figure 5. The results demonstrate that the increase in the number of tiers of the solid-core photonic crystal fiber increases the eye opening due to the decrease in the pulse width. Thus, modal dispersion reduces with increasing number of tiers.

4. CONCLUSIONS

An incident solid-core photonic crystal fiber filters the propagating modes in a multimode fiber channel, hence reduces differential mode delay and improves the BER performance of a multimode fiber channel. The pulse width of the impulse response reduces with increasing number of tiers in the solid-core photonic crystal fiber. The design does not require optimization in the optical nor electrical domain. The design may be used as an elegant alternative to current mode-filtering systems based on radial offsets, gratings, electronic dispersion compensation and holographic techniques.

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REFERENCES


