Complete modal decomposition of optical fields in step-index fibers

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This poster presents the experimental procedure for decomposing optical fields into their eigenmodes using computer-generated holograms (CGH). With this method arbitrary beam-profiles emerging from step-index fibers, can be characterized in real-time.

Introduction

The call of industry and research for guiding high power optical fields by means of step-index fibers makes it necessary to enlarge the core size of waveguiding structures. This veering away from single mode condition causes a certain beam quality loss, due to the appearance of higher order mode content [1]. A simple experimental procedure using a CGH enables to measure both modal weights and intermediate phases of investigated beams in real-time. Since the full information about the optical field becomes available, not only beam-quality characterization is possible but also the investigation of the modal behaviour of disturbed fibers.

Modes of step-index fibers

Starting from Helmholtz’ equation, describing the spatial structure of monochromatic light and under the assumption of a weakly-guiding step-index fiber one obtains the linear polarized (LP) modes as solutions of the eigenvalue problem. These modes build a finite, orthogonal and complete set of eigenfunctions \( \{ \psi_n \} \), so that an arbitrary scalar field \( U(\mathbf{r}) \) can be decomposed:

\[
U(\mathbf{r}) = \sum_{n=1}^\infty c_n \psi_n(\mathbf{r}),
\]

with the complex-valued mode coefficients \( c_n = \int \psi_n^* U dV \).

\[
c_n = \int \psi_n^* U dV \quad \text{for} \quad n = 1, 2, 3, \ldots
\]

 Experimental results

As experimental results different near-field beam profiles have been measured by CCD1, modally decomposed (by MODAN, FL & CCD2) and numerically reconstructed according to Eq. 1.

In Fig. 4 a single-mode like profile is displayed. However, the mode analysis exhibits, that \( \approx 17\% \) higher order mode content exists. The correlation coefficient \( r \) between measured and reconstructed intensity distribution is higher than 0.98.

Fig. 6 demonstrates the ability of the method to achieve the full information about the optical field. The intensity and the reconstructed phase distribution - in this case a vortex-structure - is pictured.

MODAN and experimental setup

In the case under consideration, we need information about modal strengths \( \phi_n^2 \) as well as about intermediodal phases \( \psi_n \). A suitable corresponding transmission function is known and implemented in the CGH (called “MODAN”, mode analyzer) as a binary amplitude mask, encoded by Lee-method.

The system under test is a commercial LMA fiber with \( \phi \). As a consequence, in one polarization state a maximum of six modes can be excited and correspondingly many “channels” are included. For each intermediodal phase measurement two more channels are added into T [4]. In the lasers are MO1, MO2, P, L, BS, MODAN, FL, M, CCD1, CCD2.

Fourier-plane behind the illuminated MODAN (Fig. 3, CCD1) one obtains a correlation pattern, containing the field information (Fig. 2). The required buildup is shown in Fig. 3. It essentially consists of a simple 2l-setup - the major advantage of our method.

Conclusion and Outlook

We introduced an in-situ characterization method for measuring the full field information about optical fields. With a low cost experimental realization it is possible to determine the fractional power of excited modes and their phase distributions - even for unusual beam profiles, e.g. ring-like structures. For this reason it is also conceivable to characterize the step-index fiber fields by the beam-quality factor (M-parameter) [1]. Furthermore the mode propagating properties of disturbed and bended fibers, that are changing their mode contents (mode-decoupling, polarization effects, power-loss) can be investigated.

Fig. 1: Intensity distribution of the six lowest order LP-modes

Fig. 2: Correlation pattern

Fig. 3: Experimental setup: MO1, MO2 - microscope objectives, P - polarizer, L - imaging lens, BS - beam-splitter, FL - Fourier-lens, M - mirror

Fig. 4: (a) measured near-field, (b) reconstruction result, (c) modal statistics

Fig. 5: (a) measured near-field, (b) reconstruction result, (c) modal statistics

Fig. 6: (a) measured near-field, (b) reconstruction result, (c) 3D-phase front. Modal weights: P(LP11) = 15 %, P(LP21) = 36 %, P(LP31) = 17 %

References:

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