Optical dendrites for spatio-temporal computing with few-mode fibers

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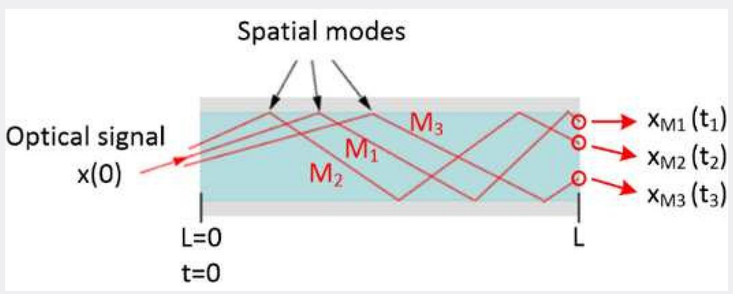
Abstract

Multimode fibers have been recently considered for optical computing, by exploiting the complex spatial and spatio-temporal transformation at the fiber end. Mimicking the dendrites of real neurons, we consider here the spatial modes that propagate with different group velocities along the fiber as different dendritic branches. The multimode fiber plays the role of an **optical dendritic unit (ODU)** and the signals obtained from the different dendritic branches are temporally mixed and used for spatio-temporal information processing. We numerically demonstrate the use of a step-index, **few mode fiber (FMF)** as a linear computing element, in a spatio-temporal coincidence detector that operates at 40 Gb/s data encoding rate. We evaluate this detector as a linear classifier in header recognition and bit counting tasks.

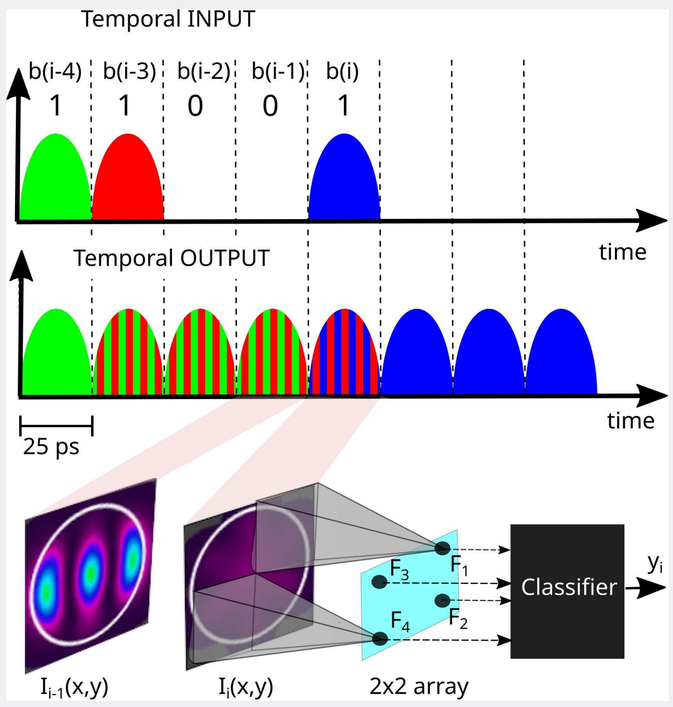
FMF-based ODU concept

The temporal mixing of an input signal occurs as it propagates through the FMF with different group velocities, via the different spatial fiber modes. The temporal mixing of the different modes introduces a short-term memory of time-encoded information.



FMF-based ODU computational operation

A digital binary encoding is represented by the presence (“1”) or absence (“0”) of a 25ps Gaussian optical pulse. A spatio-temporal intensity pattern at the output of the FMF for each **ith** input bit, **$I_i(x,y)$** is obtained. This is calculated by time-integration of the intensity of the electric field, over the pulse duration, at the FMF output. The number of output features, that one can utilize in a logistic regression classifier to execute computing tasks, depends on the photodetection approach (single-area or segmented photodetectors (2x2 and 3x3 arrays).



The two-colored striped pulses at the output sequence indicate the temporal mixing of the encoded input information with the corresponding color. By using a photodetection 2x2 array, 4 feature values (F1-F4) become available to train the classifier and give the estimation $\mathbf{y_i}$ of the corresponding input encoding $\mathbf{b_i}$.

Bibliography and Acknowledgments

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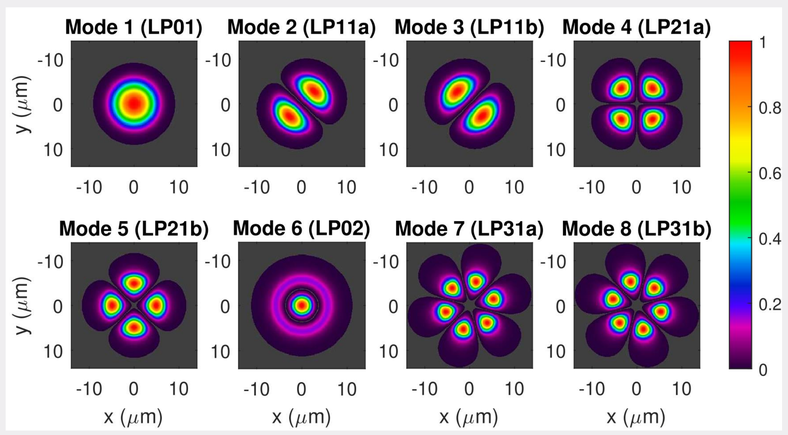
FMF design

Refractive index difference core/cladding: 0,0139
FMF core diameter: 14 μm
FMF length= 4,5 meters
Linearly polarized (LP) modes supported (1550nm): 8

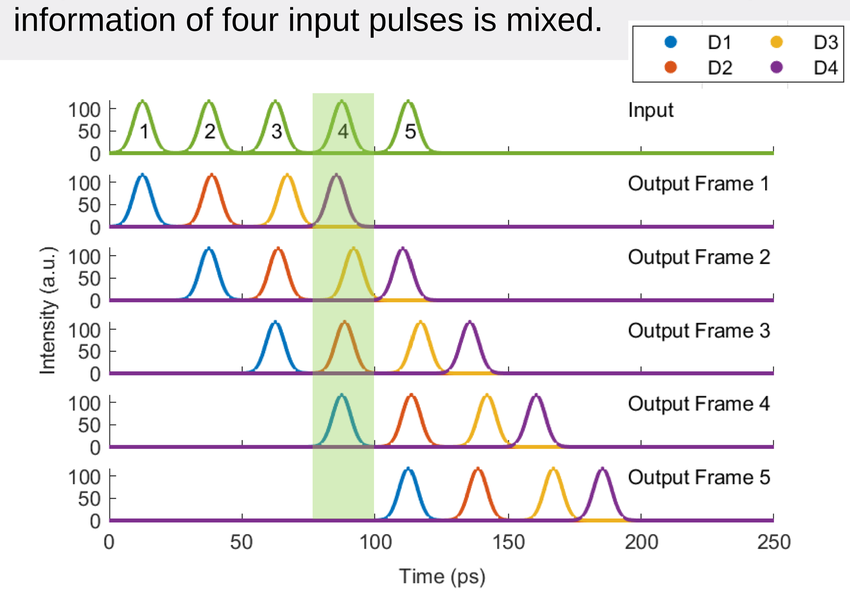


Modes with the same group velocity contribute to the signal of the same dendritic branch **D**:

D1: LP01	**D2: LP11a / LP11b**
D3 : LP21a / LP21b/ LP02	**D4: LP31a /LP31b**

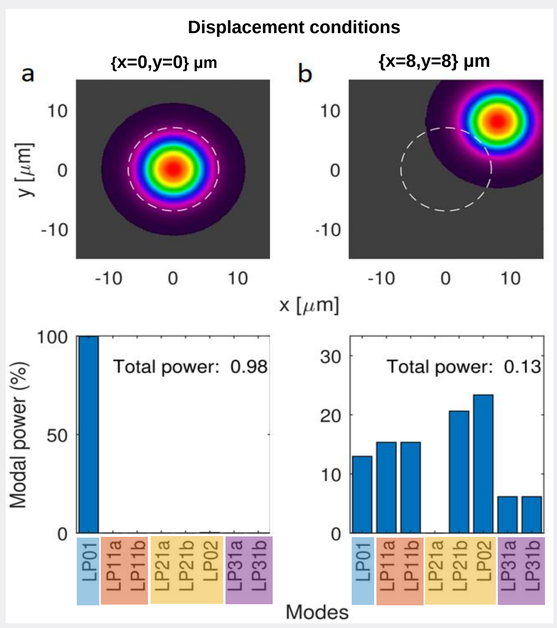
Temporal response at the linear FMF output

Five 25ps Gaussian pulses launched sequentially at the input of the FMF. Each of the input pulses propagates along the FMF with four different group velocities (dendritic branches D1-D4). Input pulse #1 results in the output frame #1, etc. Within a time window of 25ps, the information of four input pulses is mixed.



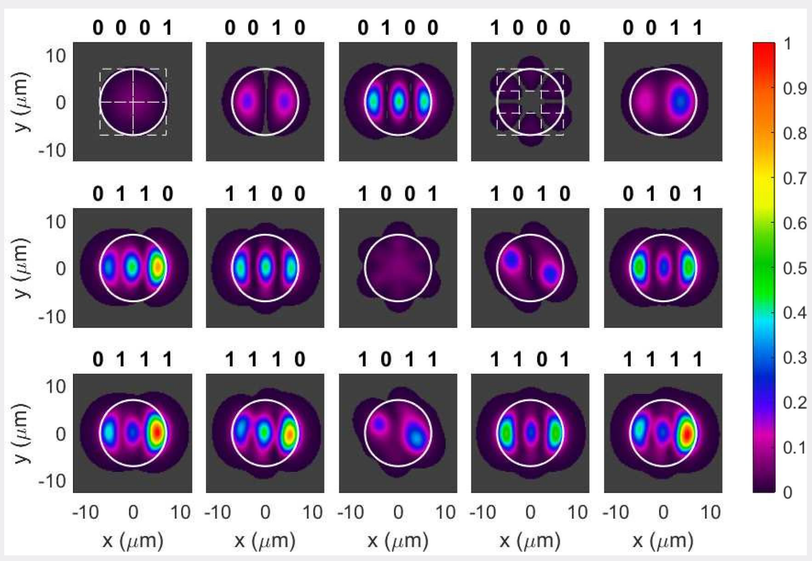
Activation of dendrites

By introducing a coupling displacement at the input, between the incident beam and the FMF fiber axis, we control the number of active dendritic branches, via the spatial fiber modes that are excited.



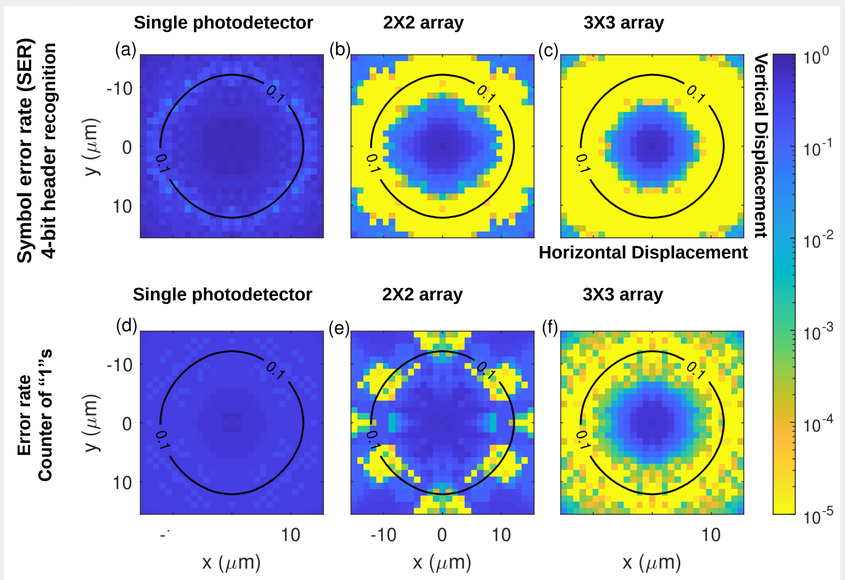
Spatial intensity pattern at linear FMF output

Depending on the input sequence pattern and the coupling displacement, we obtain different spatial intensity beam profiles at the output



Example: Normalized spatial intensity distribution at the FMF output, for 4-bit encoding patterns and for {8,8} μm input coupling displacement.

ODU classification performance



Target estimation $\mathbf{y_i}$ for the input bit $\mathbf{b_i}$ for two temporal tasks:

1. 4-bit header recognition: $\mathbf{y_i} = (\mathbf{b_{i-3}}, \mathbf{b_{i-2}}, \mathbf{b_{i-1}}, \mathbf{b_i})$
2. "1"s counter of the 4-bit header : $\mathbf{y_i} = \sum_{\{i-3\}}^{i} \mathbf{b_i}$