Integrated Structured Light Architectures: A Review of Modulation Techniques

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Integrated Structured Light Architectures: A Review of Modulation Techniques

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ABSTRACT

Coherent beam synthesis performed using phase arrays and femtosecond pulses has successfully demonstrated the ability to shape optical vortices and topological vector fields in a configuration that is power-scalable. The following is a review of the methods used and an exploration of beam parameters within computational models generating coherent beam synthesis.

INTRODUCTION

Spatial light modulators enable the control of light properties, including the field vector, amplitude, and phase distribution, allowing the characterization of light with optical vortices and topological vector field properties. These attributes find application in optical communications[3], sensing[4], and particle trapping[5] and look to be explored in molecular physics[6-8], nonlinear optics[9] and beyond. Common methods to shape light include spatial light modulators faces limitations due to its operational damage threshold, particularly when manipulating ultrashort pulses with moderate to high peak or average power levels. This work aims to demonstrate a new configuration in beam synthesis that is power-scalable featuring continuous amplitude modulation, active polarization and carrier-envelope phase (CEP) modulation.

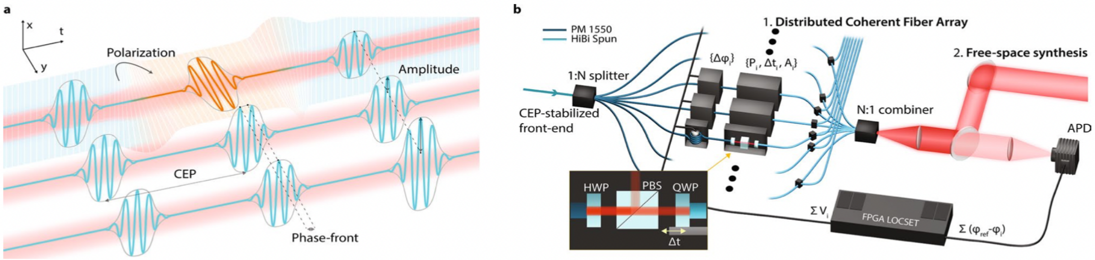

Figure 1. (a) depiction of coherent optical comb and primary elements (b) experimental configuration featuring coherent multi-channel fiber array (Ref[1], fig. 1).

METHODS

This work presents a laser architecture (Figure 1) capable of generating spatio-temporal wavevector distributions through optical combs capable of controlling field-amplitude, carrier-envelope and relative phase, and polarization.

A femtosecond laser is split into N = 7 + 1 beamlines where they are CEP stabilized and a single beam is set as a reference in order to monitor the relative phase offset across the beamlines employed by a custom field programmable gate array (FPGA) phase locking technique. After establishing a phase relationship, the beams are passed into the phase modulators (PM) where a voltage from the light can cause the piezoelectric transducer to change lengths and delay the waveforms deterministically.

With phase coherence established each beamline is sent to intensity and polarization vector control units each consisting of a halfwave plate (HWP), polarizing beam splitter (PBS) and a quarter wave plate (QWP) for timing[1]. The HWP is responsible for intensity modulation while the PBS and QWP handle polarization modulation. Once modulation has occurred, fibers maintain each beamline's polarization state prior to free space synthesis using a tilted microlens array creating a hexagonal beamline arrangement that is projected onto a photodiode for observation. The result is a programmable laser architecture capable of free-space light bullet synthesis as either an array of beamlines or a hybrid of free-space and fiber beamlines.

Establishing and maintaining coherence across all beamlines within the system is pivotal in successful free-space synthesis following primary property modulation. Phase reference is achieved using an FPGA-based LOCSET (Locking of Optical Coherence via Single Detector Frequency Tagging) technique where incoming channels are overlapped onto a single photodiode (PD), thus maximizing the amplitude seen by the diode. For this application an avalanche PD is used as its increased carrier production results in greater sensitivity compared to PIN PD. With these characteristics in mind using a LOCSET allows for power scaling and phase locking across multiple channels.

The effects of increased beamlines are explored using a numerical model capable of reconstruction and optimization of complex field synthesis[10-11]. Figure 2 illustrates the constructive interference by combining beamlines yielding increased ideal behavior proportional to the number of beam channels. This modeling algorithm was used to independently study the effects of beam waist on amplitude intensity, near field, far field and phase distributions. As shown in figure 3, increased waist size results in increased uniform amplitude within the beam cross sectional area. Such behavior is expected as increasing waist in a Gaussian beam reduces peak intensity[12]. Furthermore, changes in near-field and far-field intensities show a slight decline in resolution across waist span 1mm - 3mm with no noticeable changes from waist 3mm - 12mm. Other tunable parameters for hex tiling include number of rings, x,y-aperture and distance between beams.

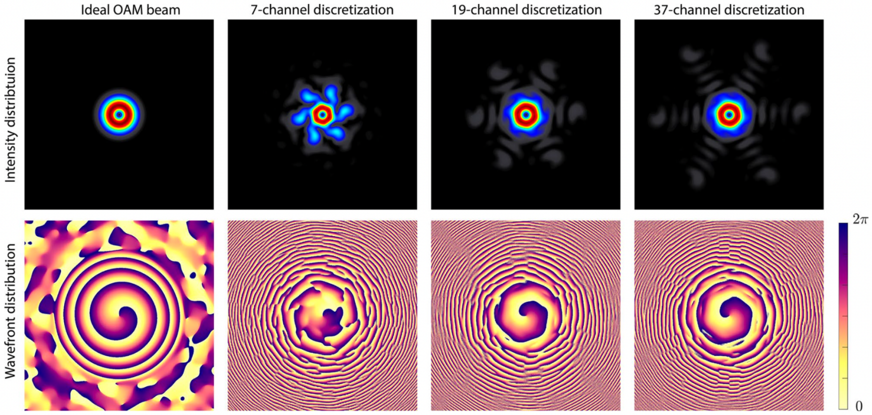

Figure 2). Row 1: Modeled first Order OAM beam intensity, Row 2: ideal wave front distributions (Ref[1], fig. 5).

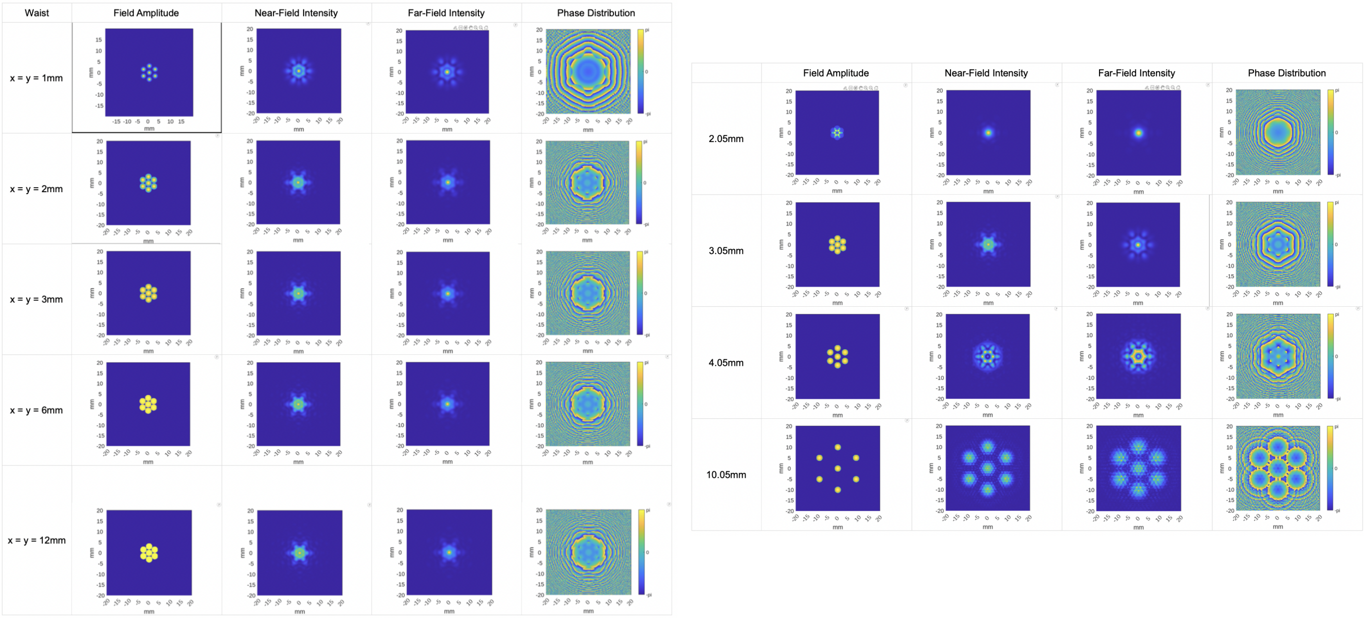

Figure 3). a) Modeled field amplitude, near-field intensity, far-field intensity and phase distribution across varying Gaussian beam waists. b). Modeled field amplitude, near field intensity, far-field intensity and phase distribution with beam waist = 3mm and varied distances between beams.

RESULTS AND INTERPRETATION

The architecture presented in this work unifies the functionalities of amplitude modulation, phase modulation and spatio-temporal modulation to generate a programmable free-space light bullet. In addition, a key finding is the relationship between the number of channels and the resolution of near-field and far-field intensities for orbital angular momentum (OAM) beams. As the configuration becomes more discretized errors from small misalignments and imprecisions of various mechanical components are averaged out. Generating a spectrum of beams and recombining them significantly improves clarity of the topological charge distribution.

The work[1] and referenced literature[10-11] lack sufficient information on the setup which is being modeled and how parameters affect the system as a whole. Through output analysis, the number of rings changes the number system channels, x,y-aperture manipulates the radius of the beams, and distance between beams influences the spacing between each individual beam. Unlike beam waist, manipulating the distance between beams significantly varies the near-field, far-field and phase distribution patterns most likely due to change in interference amongst the beams (figure 3b).

CONCLUSION

This work demonstrates a new technique for generating light with tailored spatio-temporal wavevector distributions that are programable and verifiable through numerical methods of reconstruction. With modular design principles in mind, this architecture has great potential in applications requiring finely tuned photonic structures.

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