Title

Modulation Techniques in Structured Light Architectures

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Abstract: One of the benefits of opto-electronic communication systems is their ability to transmit information using not only amplitude and phase modulation but also polarization which exploits the same set of photonic devices.

INTRODUCTION

As the demand for communicating information grows exponentially, power dissipation and information density become more important. Optical communication systems are viable solutions to both of these obstacles. They presents four degrees of freedom, namely amplitude, phase, polarization and timing which implies more information can be transmitted per unit of time[1]. Fig.1 shows a setup that allows a user to dynamically control these parameters using a field programmable logic array (FPGA)[1]. The focus of this paper is on the underlying mechanism behind the phase, amplitude and polarization modulation.

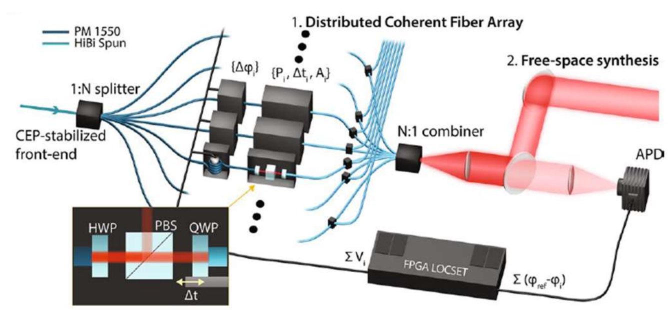

Figure 1. System level design (Ref [1], Fig 1)

METHODS

The change in phase is achieved by phase modulators with the use of piezoelectric transducer based fiber stretchers. One way to implement such module is by winding the optical fiber onto a piezoelectric tube. When voltage is applied, the diameter of the tube changes, which in turn changes the optical path length. Given the phase of a wave is a relative quantity, it is vital to ensure the phase of all the beams are consistent prior to any modulation. Hence the carrier envelope phases (CEP) must be stabilized at the beginning[1]. Furthermore, the phase of any output light needs to be measured relative to a reference wave. To do so, the FPGA in Fig.1 is phase locked to one of the channels which serves as the reference[2].

Looking into the polarization vector control unit, the linearly polarized wave goes through a half-wave plate. Equation 1 shows how the thickness of such plate can be calculated given the wavelength and indices of refraction along each axis[2]. A uniaxial or biaxial crystal can be used for this purpose such that the two principal axes parallel to the wave front (in this case $\hat{x}$ and $\hat{y}$) have different indices of refraction[2].

$$l_{\lambda/2} = \frac{\lambda}{2|n_y - n_x|} \quad (1)$$

It is worth mentioning the thickness of the HWP can be any odd integer multiple of $l_{\lambda/2}$. Once the thickness is determined, the polarization angle of the outgoing wave can be adjusted by changing the angle θ between the direction of the incident linear polarization and one of the principal axes by rotating the crystal[2]. This technique will result in a 2θ rotation of the polarization direction[2].

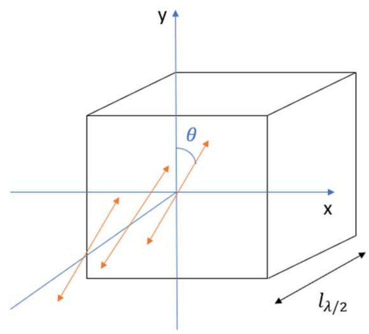

Figure 2. Orientation of the HWP

Next, the light interacts with a polarizing beam splitter (PBS). Depending on the new polarization direction, a fraction of the intensity (F) passes through the PBS while the rest (1-F) gets deflected. Therefore, the amplitude can be controlled by changing the angle θ of the HWP. Further manipulation of polarization is possible by converting the linearly polarized wave into an elliptical or circular polarization using a quarter wave plate (QWP) with a thickness given by equation 2 [2]. Similar to the HWP, an angle α can be defined between the linear polarization direction and one of the axes. This angle controls the eccentricity of the elliptical polarization with 45° angle generating a circularly polarized output wave.

$$l_{\lambda/2} = \frac{\lambda}{2|n_y - n_x|} \quad (2)$$

RESULTS AND CONCLUSION

The far-field intensity and phase distributions measured by the photodiode and the LOCSET technique show patterns that can be generated through the manipulation of the parameters discussed earlier[1]. Figure 2 of the paper by Lemons et al., 2021, shows the received intensity and phase at the end of a channel which only modulates the amplitude and phase of the light bullets[1]. The variety of these patterns is a testament to the significant increase in information density that can be achieved by optical communications.

REFERENCES

1. *Lemons, Randy, et al. "Integrated structured light architectures." Scientific reports 11.1 (2021): 1-8.*

2. Liu, Jia-Ming. *Principles of Photonics.* (Cambridge University Press, New York, 2016)