Information Encoding and Transmission Using Spectral Switches Due to Temporal Correlation

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Abstract

A data encoding and free space communication scheme is presented in which the spectral switching of polychromatic light due to temporal correlation, around the intensity minima in a Michelson interferometer has been utilized. This method is compared with the existing schemes for data communication and its advantages and experimental constraints are also discussed.

1. Introduction

In recent years, a new branch of Optics "singular optics" has developed gradually in which the properties of the zero intensity and undetermined phase points in the optical field called "singular points" are studied [1-8]. The complex structure of optical field in the vicinity of such points leads to wave dislocations and optical vortices [2, 3]. Experimental observations of the spectra around the phase singularity in a single pinhole diffraction pattern show that at a particular diffraction angle, the diffracted spectrum splits into two halves, while at other diffraction angles the spectrum either shifts towards lower wavelengths (blue-shift) or shifts towards higher wavelengths (red-shift). This drastic change is named as "spectral switch". This switching in spectrum was obtained in the vicinity of the dark ring of the Airy pattern [5] and in the Fraunhofer region [6]. Similar studies have been made in the region of phase singularity of the focused waves [7]. One of the proposed applications of spatial coherence based spectral switches was encoding data for free space communication [8, 9]. Recent study by Maruthi et al [10] showed that spectral changes take place in the neighborhood of dark fringes in the interference pattern produced due to temporal correlation in Michelson interferometer by using a white light source. In this study the red shift, blue shift and two peak spectrum were obtained for different values of the path difference introduced by moving a mirror in one of the arms of the interferometer. However, this experimental system appears rather clumsy.

We propose a user friendly system with rather modified and easily achievable parameters and its potential application for data encoding and free space communication is reported. In this scheme, a bit is encoded in terms of red shift or blue shift of the source spectrum at the transmitter end, and after transmitting up to appreciable distances through free space, it is decoded at the receiver end. Information encoding and transmission using this kind of spectral switches might provide an edge over the recently proposed encoding schemes for free-space communications [8, 9] is discussed in detail.

2. Spectral Switches Due to Temporal Correlation

The spectrum of a white light source shows anomalous behavior when observed in the vicinity of a dark fringe in an interference pattern due to temporal correlation. In the Michelson interferometer, the mirror in one arm is kept fixed while the other is moved along the beam direction using an ultra precision nanopositioner [figure 1]. A fiber-coupled spectrometer is used to measure the spectrum at the observation plane. The tip of the fiber is put on the dark ring at the observation plane and is moved across to observe spectral shift.

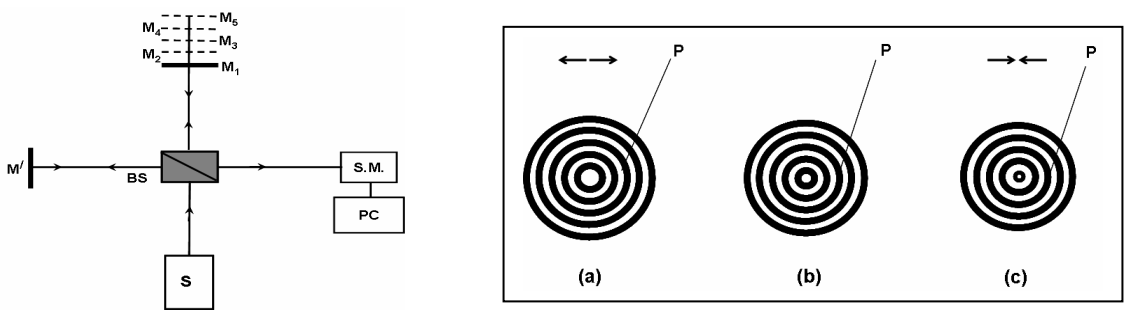

Figure 1: Schematic of a Michelson interferometer. S is a white light source, $M^{/}$ is the fixed mirror and the dash lines from M_1 to M_5 represent the positions of the moving mirror for source spectrum, red shift, two peak spectrum, blue shift and again source spectrum respectively. BS is the beam splitter; S. M. is a computer controlled spectrometer. (In inset) Movement of the observation point P. **(b)** For M_3 position the point P is at the center of the dark ring. **(a)** When the path delay is increased (M_4 position), the fringes move outside and, the point P moves inside. **(c)** For M_2 position, the path delay decreases and as the fringes collapse toward the center, the point P moves outside.

The same observation is made in an alternative way by making the fiber tip fixed, and introducing a path difference between both the arms of the interferometer by changing the position of the moving mirror. This change in the path delay makes the interference fringes at the observation plane either collapse toward the center or emerge out from the center (refer to inset of figure 1). This converging or diverging nature of the fringes shifts the position of the point P at the dark fringe. Thus the change in source spectra is recorded with the change in path delay. When the moving mirror is at position M_1 (figure 1), distances between the beam-splitter and mirrors in both the arms are the same (within experimental uncertainty). This keeps the path difference close to 0 and at the observation point we get the source spectrum without any shift (figure 2). Moving the mirror at M_2 position makes the path difference 0.78 µm and we get the maximum red shift. At position M_3 the path difference becomes 0.95 µm and the spectrum splits into two asymmetric peaks having equal intensity. The position M_4 is achieved by moving the mirror in the same direction where the path delay becomes 1.12 µm and we get the maximum blue shift. At position M_5, for the path difference of 1.33 µm, the source spectrum without any shift will be retraced.

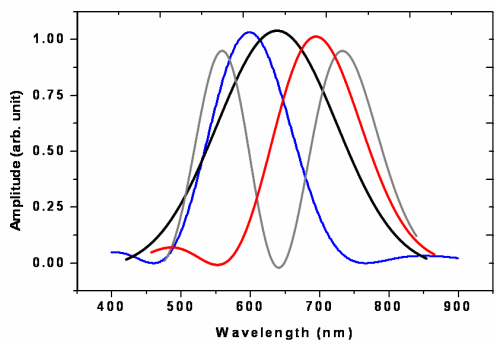

Figure 2: The spectral shift in the normalized source spectrum for different path delays $\Delta\lambda$. Spectrum shown by black line corresponds to the source spectrum for $\Delta\lambda \approx 0$. Red line shows the red shifted spectrum for $\Delta\lambda = 0.78\,\mu m$. Grey line and blue line signify the two peak spectrum ($\Delta\lambda = 0.95\,\mu m$) and the blue shift ($\Delta\lambda = 1.12\,\mu m$) respectively.

If $S_0(\lambda)$ is the source spectrum and $\Delta\lambda$ is the path difference between the two interfering beam paths, then the spectra at any point in the observation plane $S(\lambda)$ can be calculated as [10]

$$S(\lambda) = \frac{1}{2} S_0(\lambda)\left[1 + \cos\left(\frac{2\pi}{\lambda}\Delta\lambda\right)\right] \tag{1}$$

Figure 2 shows normalized values of $S(\lambda)$ for different values of path difference $\Delta\lambda$. The theoretical curves clearly indicate the spectral shift (spectral switch) for appropriate path delays. The use of a collimator with the white light source gives straight interference fringes along with the spectral switch.

3. Data Encoding and Transmission Based on Spectral Switches

For the purpose of data encoding, the data is taken in the digital form, i.e. in bits. Taking the two peak spectrum as a reference, the shift towards one end of the spectrum if is associated with a bit of information say ‘‘1’’, the shift in the other direction will be associated with ‘‘0’’. For example, let the data to be encoded is 010010110. As shown in figure 3, each bit “0” and “1” could be associated with blue shift and red shift respectively. For blue shift, the moving mirror will take M_4 position (refer to figure 1). The position M_2 will be occupied by the mirror for the red shift. Thus the whole data could be encoded accordingly (figure 3). It is worthwhile to mention here that the path delay is not well specified for any kind of spectral shift. The user can choose any arbitrary value, out of the possible values for that shift. As example for red shift, the path delay could have any value between 0.70 µm to 0.80 µm. In the same manner, for blue shift the path delay can be assigned any value between 1.10 µm to 1.20 µm.

To utilize the above mentioned scheme of data encoding, an optical communication system could be designed (figure 3). The self-similarity of the far-zone spectrum makes it possible to transmit the information over appreciable distances. The system similar to other conventional ones consists of two ends, i.e. transmitter and receiver. The simplex, i.e. only one way communication is taken into account. The transmitter consists of a Michelson interferometer with a high intensity white light source. The path delay is introduced by moving the mirror using a motorized nanopositioner. The data to be transmitted may be entered in any of the specified languages. The computerized system will convert this data into a series of 0’s and 1’s. The system will take the data sequentially and the computer algorithm will determine the movement of the mirror for the specified value of the data, i.e. 0 or 1. Once the data bit is converted into the predefined spectral shift, it is transmitted to the receiver through free space.

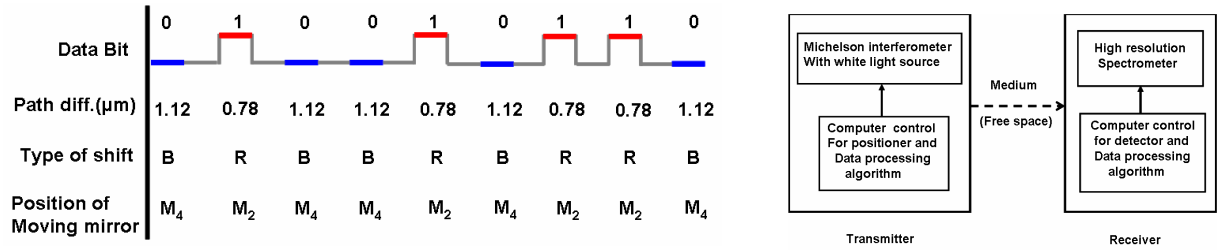

Figure 3: The data encoding scheme for a bit string 010010110 along with the free space communication scheme. The bit “1” is associated with red shift and “0” with blue shift corresponding to 0.78 µm (M_2) and 1.12 µm (M_4) path delays respectively. The transmitter consists of a white light interferometer, computerized positioner and algorithm. At the receiver end, a fiber coupled, high resolution spectrometer is used with competent computer algorithm.

At the receiver end, a computer controlled fiber coupled spectrometer with competent algorithm could be used. The system would be prealigned with the transmitter and the fiber tip locates the observation point at the fringe pattern. The transmitted spectra from the transmitter could be measured by the spectrometer. A predefined time delay between successive data bits could separate the spectral shifts from one another. To make the system more accurate, acknowledgement methods with error detection and correction algorithms could be implemented.

4. Comparison with Existing Schemes: Advantages and Limitations

In the PCM (Pulse Code Modulation) scheme of digital communication the data of any language is first converted into a series of 0’s and 1’s and then each bit of data is transmitted in the form of a well shaped pulse of appropriate voltage level. It is received at the receiver end and gets converted into the data bit according to the voltage level. In this scheme at the receiver end if by any means the incoming pulse become distorted (due to noise) and the voltage level for 1 bit changes to voltage level for 0 bit, the whole data becomes useless. In spectral switches based data transmission, the 0 and 1 bit are converted into the red and blue shifts, i.e. using appropriate frequency levels. As the noise affects the amplitude of the signal, the proposed system, remains immune to noise. The receiver, being a sensitive spectrometer reads the spectral shift only and thus shows less affinity to noise.

Since, in reference [8] and [9], the spectral switch is obtained either by modulating the spatial coherence of the source or by changing the diffraction angle. However, in temporal coherence based spectral anomalies, spectral switch is achieved by changing the position of the moving mirror along the direction of the beam. Not only are the

interference fringes obtained in a temporal coherence based system (Michelson interferometer) sharp but are easier to obtain also as compared to the spatial coherence based system (Young's apparatus).The loss of light could be minimized by using high quality optics (mirrors, beam-splitters), fiber coupled devices (source, detector) and making the system compact while in spatial coherence based systems, a compromise between intensity and visibility of fringes is unavoidable. Using interference filter, the temporal coherence of the source could be increased providing ease in obtaining the fringe pattern. The system could be made faster by placing ultra thin mirrors at positions having appropriate path delay and switching them up and down within μsec time intervals.

Though the proposed system might be efficient for data encoding, data communication and noise reduction; it might be complex in its realization. The alignment of optics, the resolution and sensitivity of detector, high precision of the nanopositioner, and competency of the algorithm are the key issues which need technical sophistication and expertise. Unfortunately, due to some mechanical aspects, the speed of the system might not compete with its electronic counterparts and also the system being raw, the data security, information hiding and cryptography issues are yet to be addressed. More research is needed to resolve the intricacies of the system to make it fast, cost effective and useful for commercial and strategic purposes. Although diffraction-induced spectral anomalies have been investigated for more than a decade and numerous applications have been found but in the perspective of data encoding and data transmission, temporal coherence based spectral anomalies might win the race.

5. Conclusion

A method for information encoding using the spectral anomalies due to temporal correlation in a white light interferometer is proposed with the potential application in data transmission. It is shown that by proper choice of path delays between the two arms of the interferometer, the spectrum at the observation point could be red shifted or blue shifted associating the data bit "1" and "0" respectively. This scheme is investigated for free space communication describing its advantages and limitations over its peers.

6. Acknowledgements

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7. References

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