Optical Phase Shift Study of Optical Devices using MZI for Signal Processing Application

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Abstract

This paper describes the measurement of optical phase shift of polarized light in the optical devices using Mach-Zehnder interferometer (MZI). The case of one light source traveling into the interfermerter, with one modulated path using the optical devices such as single mode fiber, polarization maintaining fiber, nonlinear sammarian fiber, erbium dope fiber and $LiNbO_3$ (lithium niobate) are investigated. The behavior of signal outputs obtained of each case is detected and plotted, then discussed the use of such a device for phase shifter or switching. The optical output signal characteristic of the detected signal can be analyzed for the potential of using in the case of device modeling and design, either for optical sensors or communication application. Preliminary results have shown that the one using polarization maintaining fiber showing the phase shifter characteristic.

Keywords: optical signal processing, optical modulator, optical phase shift

1. INTRODUCTION

The optical phase shift of polarized light in the optical devices using Mach-Zehnder interferometer for measurements were widely used in many areas of application [1-2]. Most of them use intensity or phase shift of the optical field to form the required measurement information, The MZI interferrometric techniques were investigated using interferometer is one of the optical instrument that has been popularly used for measurement and instrumentation. [3-5] While the use of such devices for signal processing and communication are presented. [6-8] In this work, we modulate one arm of the in terferometer to form the optical device and their characteristics such as optical phase shifter. Where the experimental modeling is set in the laboratory, where the variation of optical medium can be employed to generate the optical phase shift the output behaviors is presented by using quantum approach.
2. are characterized. Where is the system calculation.

2. THEORETICAL BACKGROUND

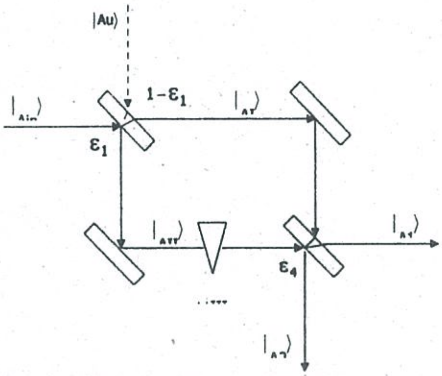


Figure 1 the schematic diagram of the MZI system.

Generally, the interferometer is an instrument that has been widely used either in classical or modern optics. The quantum model of the MZI is used to describe for the generalized calculation, the schematic diagram of the system is as shown in Figure 1.

This is an evaluation of the output signal of and interferometer with two beamsplitters, one with reflectivity ε_1 at the input and a second with reflectivity ε_4 for recombining. The waves inside the interferometer are given by

$$|AI\rangle = \sqrt{1-\varepsilon_1}\,|Ain\rangle - \sqrt{\varepsilon_1}\,|Au\rangle$$

$$|AII\rangle = \sqrt{\varepsilon_1}\,|Ain\rangle + \sqrt{1-\varepsilon_1}\,|Au\rangle \quad (1)$$

The two output waves are given by

$$|A1\rangle = \sqrt{1-\varepsilon_4}\,e^{i\Delta\phi}|AII\rangle - \sqrt{\varepsilon_4}\,|AI\rangle$$

$$|A2\rangle = \sqrt{\varepsilon_4}\,e^{i\Delta\phi}|AII\rangle + \sqrt{1-\varepsilon_4}\,|AI\rangle \quad (2)$$

For the balanced case, $\varepsilon_1 = \varepsilon_4 = 1/2$, we obtain

$$|A1\rangle = e^{i\Delta\phi/2}[\sin(\Delta\phi/2)|Ain\rangle + \cos(\Delta\phi/2)|Au\rangle]$$

$$|A2\rangle = e^{i\Delta\phi/2}[\cos(\Delta\phi/2)|Ain\rangle + \sin(\Delta\phi/2)|Au\rangle] \quad (3)$$

This leads to the expressions for the photon flux operators

$$\hat{N}_{A1} = \sin^2(\Delta\phi/2)\hat{A}_{in}^{+}\hat{A}_{in} + \cos^2(\Delta\phi/2)\hat{A}_{u}^{+}\hat{A}_{u} - \sin(\Delta\phi/2)\cos(\Delta\phi/2)\left(\hat{A}_{in}^{+}\hat{A}_{u} - \hat{A}_{u}^{+}\hat{A}_{in}\right)$$

$$\hat{N}_{A2} = \cos^2(\Delta\phi/2)\hat{A}_{in}^{+}\hat{A}_{in} + \sin^2(\Delta\phi/2)\hat{A}_{u}^{+}\hat{A}_{u} + \sin(\Delta\phi/2)\cos(\Delta\phi/2)\left(\hat{A}_{in}^{+}\hat{A}_{u} - \hat{A}_{u}^{+}\hat{A}_{in}\right) \quad (4)$$

When light traveling into the Mach-Zehnder interferometer, the input of one coherent and one vacuum state is $|A_u\rangle = |0\rangle$ and $|A_{in}\rangle = |\alpha\rangle$ respectively, where α is real. The case of the MZI with a phase difference $\Delta\phi$ is normally considered, where the photon flux and the variance of the flux are

$$\langle\hat{N}_{A1}\rangle = V_{\hat{N}A1} = \alpha^2\sin^2(\Delta\phi/2) = N_{Ain}\sin^2(\Delta\phi/2)$$

$$\langle\hat{N}_{A2}\rangle = V_{\hat{N}A2} = \alpha^2\cos^2(\Delta\phi/2) = N_{Ain}\cos^2(\Delta\phi/2) \quad (5)$$

The phase of light traveling into the optical is changed by $\Delta\phi$ relatively to the optical path difference between two paths of traveling light in the interferometer. The output signals are detected characterized in order to experimentally modeling of the optical signal processing devices such as phase shifter, switching and demultiplexer etc. The term of phase change $\Delta\phi$ can be induced by modulation in one arm of the traveling light paths that can be replaced by the optical fiber or optical materials. The induced phase change is given as

$$\Delta\phi = \frac{2\pi}{\lambda}nl \quad (6)$$

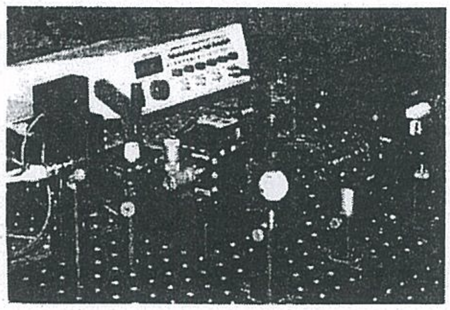
The detected ac signal is largest when the change in power is most rapidly changed, that is when $\Delta\phi = \frac{\pi}{2}$, at the center point between the maximum and minimum peak of the interference fringe. The signal can be compared with the variance of the photon number, or the quantum noise on the detector.

3. EXPERIMENT AND RESULTS

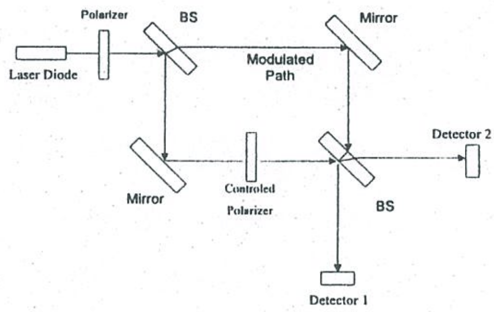
The experimental set up system is shown in Figure 2. The quantum approach is used to describe the operating system. In this work, the orthogonal light signals are formed by linearly polarized light that is modulated by the input inject current into the laser source. Light form modulated laser diode of wavelength with 670 nm, bandwidth of 500 MHz was linearly polarized and launched into the interferometer via a beam splitter (BS).

One beam was traveled to the mirror M1, and then reflected to the second BS. The another beam is traveled to the mirror M2 and then modulated by the optical modulated unit before entering into the BS, where the combination of light signals i.e. interference signals were detected by the detector, and then was shown on the oscilloscope. The modulated beam was set to offset value using a second controlled polarizer. Variation of optical mediums such as single mode fiber, polarization maintaining fiber, nonlinear sammarian fiber, erbium dope fiber and $LiNbO_3$ (lithium niobate) was employed, and then the corresponding measurement values were recorded. The good optical alignment was taken care to avoid the interferometric noises while the measurement was in progress. When one mode of polarization is launched into the modulator, the coupling mode occurs due to the change of the input orientation angle (i.e. $\Delta\phi$ in equation) causing the change of the optical output power at detector 1 and detector 2, which is observed and shown in Figure 3. The optical phase shift characteristics between two channels i.e. detector 1 and detector 2 were observed using a polarizing plate. The polarization orientation angles were varied from 0 to 2π, with the maximum optical outputs.

In Figure 3 shows the phase shifter device characteristic when a length of Figure 3(a) shows graph of the results using a polarizer Figure 3(b) a single mode sammarian optical fiber of 1 meter with refractive index of 1.52 was employed as a modulator. The phase shifter characteristics between two channels were occurred when the orientation angle of degree was presented, which the signals from two channels are at in phase positions differing from the case in Figure 3(a). Figure 3(c) shows graph of the results using $LiNbO_3$ as a modulator with y-cut form, dimension of 1 cmx1cmx 1 mm showing the output intensities against the polarization orientation angles. The phase shifter characteristic is observed when the azimuth angle is degree with the S/N and crosstalk . Figure 3(d) shows graph of the results using polarization maintaining fiber an the modulated medium. The relationship between output intensities and input polarization angles are plotted. The switching characteristics is occurred when the azimuth angle degree, Figure 3(e) shows graph of the results using erbium dope fiber of 1 meter with refractive index of 1.52 was employed as a modulator The phase shifter characteristics between two channels were occurred when the orientation angle of degree was present.



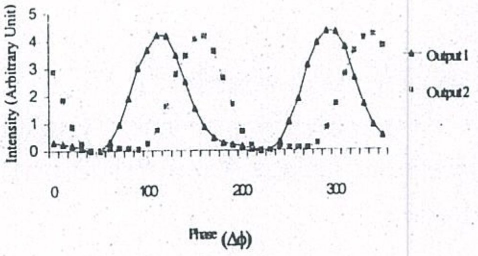
(a)



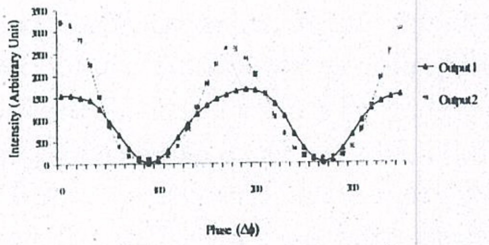
(b)

Figure 2 The experimental set up: (a) an experimental system, (b) a schematic diagram.

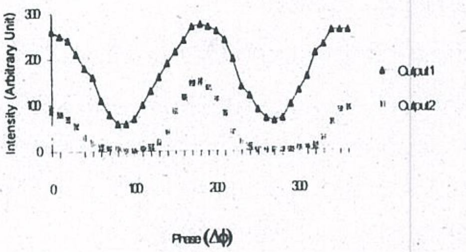
Noise effects either interferometric or quantum noises are discussed by the experimental results, where the internal reflection of light in the interferometer is the major effect, while the quantum noise inducing by the photodetector and light source property are the major effects. Thus, the combination between quantum and interferometric noises are become noise floor of measurements.



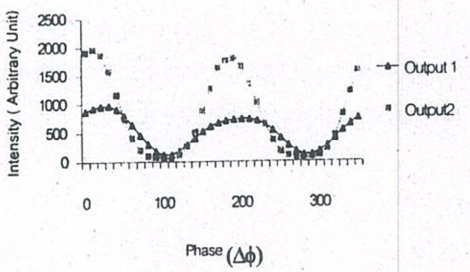
(a)



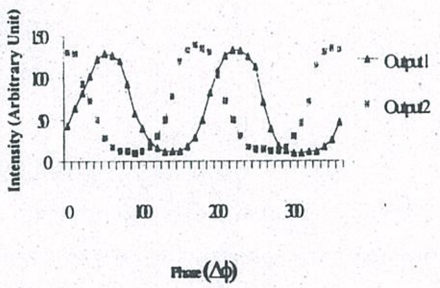
(b)



(c)



(d)



(e)

Figure 3 Graphs of the results obtained using; (a) a polarizer, (b) a sammarian optical fiber, (c) $LiNbO_3$ and (d) polarization maintaining fiber.(e) Erbium dope fiber

From results as is shown in Figure 3, the signal hopping is occurred by the interferometric noise, these noise effects can be neglected comparing to the S/N of the system. However, this effect may become the device of the optical phase shifter system, where such a good arrangement of the optical system and device property may need to realize the applications.

4. CONCLUSION

A review of quantum calculations of the MZI has been described. The applications for optical device and signal processing characterizations have also been investigated and discussed, the preliminary results using optical medium such as polarizer, sammarian nonlinear fiber optic, polarization maintaining fiber, erbuirm dope fiber and $LiNbO_3$ have shown the possibility of applications such devices for phase shifter, switching, demultiplexer and filter. The continuing work is focussed on the use of varieties of optical modulator replacing in one path of the instrument, where the modulated techniques are also employed to produce the appropriate output signals for the applications. When the optical signal characteristics can be analyzed for the use of device modeling and design either for optical sensors or communication applications.

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