# Fast and Effective Method to Distinguish the Polarizing Components Using a Polarizing Triangular Cyclic Interferometer

**Rapeepan Keawon[1*], Chutchai Pawong[2], Apichai Bhatranand[1] and Ratchapak Chitaree[3]**
[1]*Department of Electronic and telecommunication, Faculty of Engineering, King Mongkut's University of Technology Thonburi, 10140, Thailand*
[2]*Physics Division, Faculty of Science and Technology, Rajamangala University of Technology Krungthep, 10120, Thailand*
[3]*Department of Physics, Faculty of Science, Mahidol University, 10400, Thailand*
*Author e-mail address: [1*]tod_dodo@hotmail.com*

**Abstract:** The application of the polarizing triangular cyclic interferometer to distinguish different types of polarizing components is investigated. The distinct output signals from polarizer and wave plates under examination can clearly be observed.
**OCIS codes:** (120.0120) Instrumentation, measurement, and metrology; (120.3180) Interferometry

## 1. Introduction

Many optical measuring techniques have been developed for investigating and characterizing optical specimens such as polarizers and wave retarders [1,2]. One of the most widely used techniques for optical investigations is based on interferometry. Various types such as Michelson, Mach-Zehnder and Fabry-Perot interferometers are among those commonly employed in optics laboratories [3]. However, some limitations exist such as the number of optical components used and alignment difficulties may deter the usage of these arrangements. In this study, so called polarizing Triangular Cyclic interferometer (pTCi) is proposed as an alternative which requires less optical components and a fewer steps for setting up [4-6]. The interferometric configuration has successfully been used to generate an optically controllable azimuth and high quality linearly polarized beam [7]. In this study, a unique modification of the polarized output from the pTCi is used to separate different types of polarizing components inserted in the arrangement. The mathematical model for verifying the experimental result is simplified by Jones calculus [8,9]. The mathematical treatment provides an obvious insight that is comprehensible and easily comparable with the output signal. Linear polarizer and wave retarders are chosen as optical components under investigation. The proposed technique provides a fast and effective way to separate those optical samples.

## 2. Theoretical Background

The basic principle for generating a unique polarized beam from pTCi is based on a phase modulation technique. A linear polarized light beam injected into the interferometer is separated equally into two orthogonal (vertical and horizontal) polarized beams by a polarizing beam splitter. The transmitted ($V_{aT}$) and reflected ($V_{aR}$) beams from each path of pTCi are given by [7]

$$V_{aT} = \frac{1}{\sqrt{2}}\begin{bmatrix}1\\0\end{bmatrix}e^{j(\Delta_o-\omega_o t)} \quad \text{and} \quad V_{aR} = \frac{1}{\sqrt{2}}\begin{bmatrix}0\\1\end{bmatrix}e^{j(\Delta_o-\omega_o t)} \tag{1}$$

where $\Delta_0$ and $\omega_0$ are initial phase and angular frequency from a He-Ne laser ($\lambda = 633$nm) respectively. Then, both beams from paths 1 and 2 as seen in Fig. 1 (a) travel through an optical sample inserted in one arm of pTCi. The electric fields of light beams can be determined from

$$V_{aT'Sample} = PBS\bullet M2\bullet Sample\bullet PZT(M1)\bullet V_{aT} \quad \text{and} \quad V_{aR'Sample} = PBS\bullet PZT(M1)\bullet Sample\bullet M2\bullet V_{aR} \tag{2}$$

where *PBS*, *M2*, *Sample* and *PZT(M1)* represent Jones matrices for polarizing beam splitter, mirror M2, an optical sample under investigation and mirror M1 attached to piezoelectric transducer, respectively. Note that the modulating frequency is given as $\Omega$. At the output of the interferometer, the two light beams recombine at PBS and then passing through the quarter wave plate (QWP) with their fast axis oriented at 45$^o$ to the PBS. A polarizer (P) is used in the output detection so as to verify the output state of polarization. The Jones vector of output beam $V_o$ can be written as

$$V_o = P\bullet QWP\bullet V_{aT'Sample} + P\bullet QWP\bullet V_{aR'Sample} \tag{3}$$

where *P* and *QWP* are Jones matrices of polarizer and quarter wave plate. The output intensity ($I$) at the detector is $I = V_o\bullet V_o^*$. The intensity outputs corresponding to optical sample types can be presented in Table 1.

Table 1. The output intensity ( $I$ ) from the different types of polarizing components.

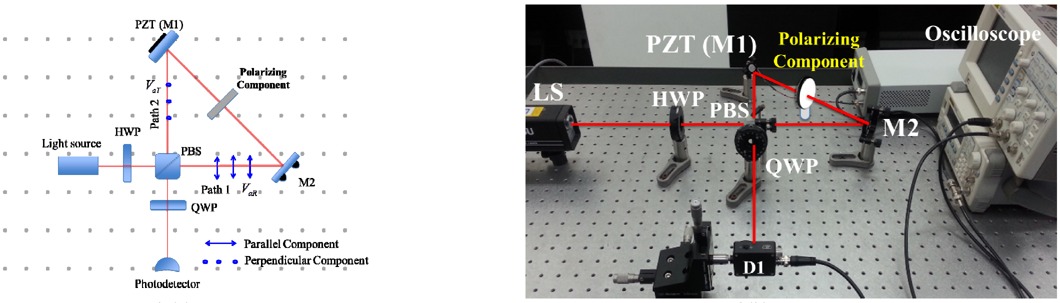
| Different types of polarizing components | Output intensity ($I$) |
|---|---|
| *Polarizer* | $I_{polarizer} \propto \frac{1}{4}[1+\sin(2\varphi+\Omega t)]^2$ |
| *Quarter wave plate* | $I_{QWP} \propto \frac{1}{2}[1+\sin^2(2\varphi+\Omega t)]$ |
| *Half wave plate* | $I_{HWP} \propto 4\sin^2[(2\varphi+\Omega t)]$ |

In the experiment, three orientations of a polarizing sample ( $\varphi$ ) was chosen to be $0^{\circ}$, $45^{\circ}$ and $90^{\circ}$ with respect to a reference direction so as to obtain three waveforms monitored by an oscilloscope. Therefore, the output waveforms provide an indicator to distinguish and identify the specimens. Note that the quality of the output beam from pTCi can be stated in terms of Degree of Polarization (*DOP*) and ellipticity (*e*). The values of the *DOP* and *e* obtained from the measurable Stokes Parameters ( $S_0$ , $S_1$ , $S_2$ and $S_3$ ) can be expressed as [10]

$$DOP = \frac{\sqrt{S_1^2+S_2^2+S_3^2}}{S_0}\times 100\% \qquad \text{and} \qquad e=\tan\left(\frac{1}{2}\left[\sin^{-1}\frac{S_3}{\sqrt{S_1^2+S_2^2+S_3^2}}\right]\right) \tag{4}$$

## 3. Experimental Setup

A schematic diagram and the experimental arrangement are shown in Fig. 1(a) and (b), respectively. The output polarized beam is monitored by a photodetector and the signal waveform is displayed on an oscilloscope.




1 (a) 1(b)

Fig. 1. (a) Schematic diagram of the pTCi setup. (b) The experimental setup of pTCi.

## 4. Experimental Results

The output without the sample from the pTCi is recorded as a reference waveform on the oscilloscope. The output result is shown in Fig. 2. Note that the reference waveform is detected after a linear polarizer. The measured Stoke parameters were found to be $S_0 = 3.46\pm0.09, S_1 = 3.40\pm0.09, S_2 = 0.06\pm0.01, S_3 = 0.05\pm0.05$ . The value of *DOP* and *e* are determined as *DOP* = $98.3\pm0.3\%$ and $e = 0.007$. The values of these quantities confirmed the state of the output beam as the rotating linearly polarized light.

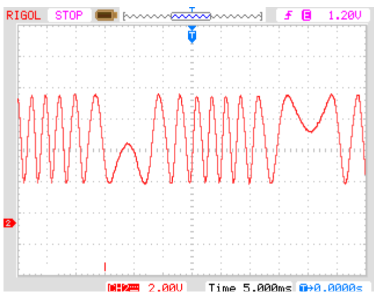
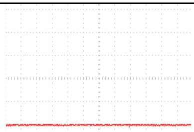
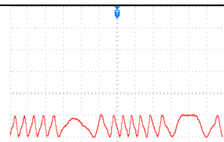
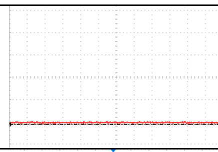
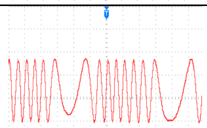
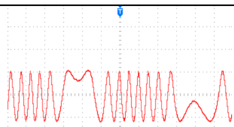
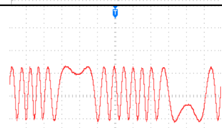
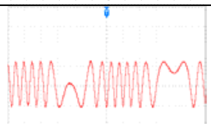
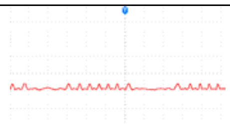
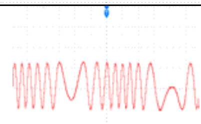



Fig. 2. The waveform of the rotating linearly polarized beam as the output signal displayed on the osciloscope from the pTCi. The signal is taken without a sample in the setup.

To test the ability of the pTCi for a fast and effective way to distinguish polarizing components, linear polarizers and wave retarders were inserted into the arrangement (Fig. 1). Because of different polarization properties introduced by each component, the output signal was modified. The waveform of the output signal corresponding to each polarizing component at particular orientations is shown in Table 2.

Table 2. Waveforms of the output signals are obtained from pTCi with insertions of polarizing components oriented at particular angles.

| Angle / Sample | 0° | 45° | 90° |
|---|---|---|---|
| Linear polarizer (LP) |  |  |  |
| Quarter wave plate (QWP) |  |  |  |
| Haft wave plate (HWP) |  |  |  |

## 5. Discussions and conclusion

Three specific orientations of polarizing components were investigated. The corresponding waveforms are illustrated in Table 2. The judgement to differentiate polarizing components under interest is discussed as follows. Output waveforms corresponding to polarizing components oriented at 0°, 45° and 90° relative to a reference direction from pTCi are closely examined. As can be seen from Table 2, the waveforms due to the introduction of a linear polarizer into the arrangement are obviously distinct from other waveforms produced by other polarizing components. The orientations of the linear polarizer at 0° and 90° result in only a single linear polarized beam left in the setup and the output from the pTCi is simply circular polarized. While the waveform at 45° gives the same state of polarization as the reference but with a smaller amplitude. The matter of distinction becomes less obvious when comparing waveforms from QWP and HWP. Under all chosen orientations, the waveforms due to the introduction of the QWP are exactly the same as the reference. This suggests that the insertion of the QWP oriented at specific directions has no effect on the operation of the pTCi. The phase shift from the QWP merely contributes to the phase modulation normally made by the PZT in the setup. The same explanation can also be applied to the two orientations, i.e. 0° and 90°, of the HWP. The waveform from the HWP at 45° becomes an important indicator which can be used to separate the insertion of the HWP from QWP. The output magnitude is roughly nil because the HWP at 45° simply diverts the two linear polarized beams from the output.

In all, the output waveforms from the pTCi have already been proved to be a valuable tool for separating different types of polarizing components under investigation. This method provides a fast and effective means of modifying the output signal from the pTCi.

## 6. References

[1] RMA. Azzam and NM.Bashara, *Ellipsometry and polarized light*, (North Holland, 1987).
[2] C. Pawong, R.Chitaree, and C. Soankwan, "Investigation the use of rotating linearly polarized light for characterizing SiO2 thin-film on Si substrate," Proc. SPIE 8308, Optoelectronic Materials and Devices, (Society of Photo-Optical Instrumentation Engineers, 2011), pp.83081I1-8.
[3] GE. Sommargren, "Up/down frequency shifter for optical heterodyne interferometry," J Opt Soc Am **65**, 960–961(1975).
[4] S. Sarkar, N.Ghosh, S.Chakraborty, and K. Bhattacharya "Self–referenced rectangular path cyclic interferometer with polarization phase shifting," Applied Optics **51**, 126-132 (2012).
[5] Y. Pavan Kumar, and S. Chatterjee, "Thickness measurement of transparent glass plates using a lateral shearing cyclic path optical configuration setup and polarization phase shifting interferometry," Applied Optics **49**, 6552-6557 (2010)
[6] Y. P. Kumar, and S. Chatterjee, "Simultaneous measurement of refractive index and wedge angle of optical windows using Fizeauinterferometery and a cyclic path optical configuration," Applied Optics **48**, 4756-4761 (2009).
[7] R. Keawon, A. Bhatranand, Y.Jiraraksopakun, E.Siwapornsathain, C.Pawong and R.Chitaree, "Generation of the rotating linearly polarized light using the triangular cyclic interferometer," ITC-CSCC 29th International Conferences, (Engineering Sciences Society and Electronics Society, Thailand, 2014), pp. 546-549.
[8] B. Kanseriand, and H.C.Kandpal, "Mathematical formulation for verification of the Fresnel and Arago interference laws using a Mach-Zehnder interferometer," Optik**121**, 1019-1026 (2008).
[9] C. Pawong, R.Chitaree, and C. Soankwan, "The rotating linearly polarized light from a polarizing Mach-Zehnder interferometer:production and application," Optics & Laser Technology **43**, 461–468 (2011)
[10] S. Suchada, B. Prapa, and K. Warunee, "Polarization state control by using rotating quarter wave plate for the measurement by light," Procedia Engineering 8, (Elsevier Ltd, 2011), pp. 243–247.