# A Novel Technique to Measure the Phase-Drift of an Optical Phase Modulator

*Ruey-Ching, Twu (1), Hao-Yang Hong (1), and Hsuan-Hsien Lee (2)*
1 : Department of Electro-Optical Engineering, Southern Taiwan University
1, Nan-Tai St., Yung-Kang City, Tainan 710, Taiwan, R.O.C.
2 : Department of Electrical Engineering, Southern Taiwan University
1, Nan-Tai St., Yung-Kang City, Tainan 710, Taiwan, R.O.C.
e-mail : rctwu@mail.stut.edu.tw

**Abstract:** In this paper, we develop a measurement system with capabilities of phase unwrapping, real-time and long-term monitoring for measuring a phase-drift caused by photorefractive effects in lithium niobate phase modulators. To extract the phase-drift variations, the experimental setup uses a homodyne interferometer with a phase-modulation and a Fast Fourier Transform (FFT) demodulation schemes.

**Keywords:** Photorefractive effects, phase modulator, lithium niobate

Lithium niobate (LN) waveguide devices exhibiting excellent characteristics of electro-optic (EO) and nonlinear optic (NLO) can provide various functions of phase modulation, polarization rotation, and wavelength conversion [1,2]. However, the higher pumping intensities easily cause unstable operations due to the photorefractive effects in LN materials. Usually, the drift directions of the photo-induced carries are anisotropic that are also dependent on the substrate geometry and externally applied voltages. Similar to the externally forced voltages, the accumulated carriers can further produce an electric field to modulate the local refractive index through EO effects. Therefore, the propagation phase of a guiding-wave is modulated accordingly. The induced phase drifts will make the output powers unstable in an EO modulator [3]. In this paper, we develop a measurement system with capabilities of phase unwrapping, real-time and long-term monitoring for measuring phase drifts of LN phase modulator due to photorefractive effects. The experimental setup uses a homodyne interferometer based on a phase-modulation and a Fast Fourier Transform (FFT) demodulation schemes, in which have been successfully demonstrated in optical metrology for both common-path and splitting-path interferometers [4,5].

Figure 1 shows a device structure and experimental setup of the proposed method for real-time monitoring the phase drifts of LN phase modulators. An x-cut/y-propagation phase modulator consisting of a channel waveguide, and a pair of electrodes, in which placed parallel and adjacent the channel was used to evaluate the photorefractive effects under various applied voltages and throughput powers. The phase delay between the TE and TM waves can be modulated by driving electric signals over the electrodes through EO coefficients of $r_{22}$ and $r_{12}$. The input powers can be controlled by changing the relative transmittance angles between polarizers of PL1 and PL2. Then, a linear polarization oriented at an angle of 45° relative to the crystal $x$-axis by controlling the relative angles between PL2 and the principle axis of half-wave plate (λ/2 WP), which is launched in the phase modulator via an object lens L1 (40×). The output beam was received by an amplified photo-detector (PD) after passing through a coupling object lens L2 (40×), a pinhole (Pin), and an analyzer (AL) oriented at –45°. For data acquisition and analysis, we use a PC-based system operating in the LabVIEW$^{TM}$ platform (version 7.0, National Instrument). The received data from the photo-detector was connected to a lap-top personal computer through a multi-channel signal box (BNC-2120, National Instrument), and a data-acquisition-card (DAQ-6036E, National Instrument). Finally, the real-time and long-term monitoring can be successfully displayed with the designed front panel. In the case of a sinusoidal voltage over the phase modulator, the interferometric signals can be further analyzed by performing with the FFT program. The phase variations including a intrinsic phase-difference $\Delta\phi$, a time-varying phase-drift $\Delta\phi^{PR}$ (t) can be expressed as:

$$\Delta\phi + \Delta\phi^{PR}(t) = \tan^{-1}\left(\frac{I_1 \cdot J_2(\beta)}{I_2 \cdot J_1(\beta)}\right) \qquad (1)$$

where $J_k(\beta)$ is the Bessel function of order $k$ with a index factor of $\beta$. The first harmonic and second harmonics of the measured spectrum are $I_1$ and $I_2$, respectively. The modulation depth $\beta$ can be represented by

$$\beta = \frac{V_{ac}}{V_\pi}\pi \qquad (2)$$

where $V_{ac}$ is the applied peak-to-peak AC-voltages; $V_\pi$ is the switching voltages for a π phase-shift between TE and TM waves in the waveguides.

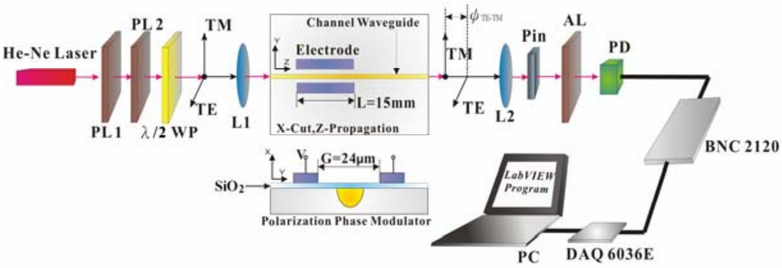
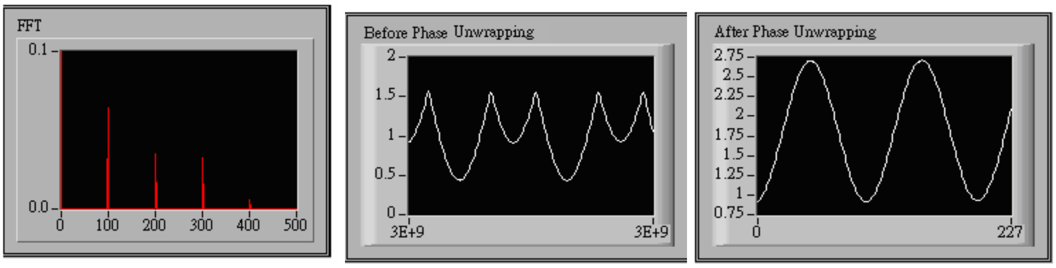


Fig. 1  A schematic of experimental setup for the phase-drift measurement system.

Several experiments are conducted to validate the performance of the optical arrangement as proposed in Fig.1. To make a single-mode waveguide for both TE and TM polarizations, a 35 nm-thick and 4 μm-wide Zn-strip with a predeposition Ni film of 6 nm was fabricated with thermal diffusion of 850°C for 150 min. After end-faces polished, a silicon dioxide ($SiO_2$) buffer layer of 300 nm was deposited. Then an Al electrode of thickness 300 nm was deposited and patterned. The gap width $G$ between parallel electrodes is 24  μm, and the electrode length $L$ is 15 mm. The analyzed FFT spectrum is shown in Fig. 2 (a). In the case of short-period and low-power operations, the photorefractive effects can be ignored. To ensure a validation of the proposed method, we input a sinusoidal voltage $V_{\mathrm{ac}}$ over the waveguide electrodes of Zn-indiffuesd phase modulator with a peak-to-peak value of 10 V and a frequency of 100 Hz at a throughput power of about 5 μW. It is assumed that the modulation speed of AC-signal is much faster the response time of the photorefractive reactions, which is typically in the order of minutes. At the same time, a slowly sinusoidal voltage with frequency of 0.01 Hz is applied over the same electrodes to produce the simulated phase-drift $\Delta\phi^{PR}$ (t) as expressed in Eq. (1). Thus, the induced phase variations are also a sinusoidal-like curve through EO effects. Since the extracted phase values after an arctan operation are within in a range from 0 to π/2, it will possibly limit the dynamic range in a real situation. Figure 2(b) gives the simulated phase variations with a phase ambiguity near π/2 (~1.57 rad). The phase ambiguity can be solved by using a phase-unwrapping technique also performed with LabVIEW$^{\mathrm{TM}}$ programs, as shown in Fig. 2(c).



(a) (b) (c)

Fig. 2 LabVIEW$^{\mathrm{TM}}$ front panel for the proposed measurement system: (a) the FFT spectrums, (b) the measured phase variations with a phase ambiguity, and (c) the phase-unwrapping signal.

In conclusion, we have successfully demonstrated a simple and novel method to measure the phase drift caused by the photorefractive effects in LN phase modulators. The signal processing is performed with LabVIEW$^{\mathrm{TM}}$-based hardware and software, which can effectively integrate the necessary functional instruments in comparison with traditional arrangements.

## References

1) R. C. Alferness, "Electrooptic guided-wave device for general polarization transformations," IEEE J. Quantum Electron. **17**, 965-969 (1981).
2) M. H. Chou, I. Brener, M. M. Fejer, E. E. Chaban, and S. B. Christman, "1.5-μm-band wavelength conversion based on cascaded second-order nonlinearity in $LiNbO_3$ waveguides," IEEE Photon. Technol. Lett. **11**, 653-655 (1999).
3) R. C. Twu, H. H. Lee, H. Y. Hong, and C. Y. Yang, "A novel Zn-indiffused mode converter in x-cut lithium niobate," Optics Express **15**, 15576-15582 (2007).
4) M. Levesque, M. Têtu, P. Tremblay, and M. Chamberland, "A novel technique to measurement the dynamic response of an optical phase modulator," IEEE Trans. Instrum. Meas. **44**, 952-957 (1995).
5) B. Sepúlveda, G. Armelles, and L. M. Lechuga, "Magneto-optical phase modulation in integrated Mach-Zehnder interferometer sensors," Sens. Actuators A-Phys. **134**, 339-347 (2007).