The study of mechanical resonances of the phase electro-optic modulator based on LiNbO₃ for noise reduction of fiber-optic gyroscope

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Abstract. We report about the study of Ti diffused LiNbO₃ x-cut electro-optic modulator (EOM). This paper describes a study of mechanical resonances induced by applied voltage in EOM and their influence on the EOM functioning. The method for reduction of mechanical resonances influence is presented. Described method can be used for noise reduction of fiber-optic interferometric sensors and fiber-optic gyroscope in particular.

1. Introduction
EOMs are widely used in fiber-optic communication systems as well as in fiber-optic sensors [1, 2]. Most of these EOMs are based on a lithium niobate (LN, LiNbO₃) crystal because of its unique properties [3, 4]. The most sensitive fiber-optic sensors are interferometric ones. An additional phase modulation is applied in these devices by using EOMs. It allows to increase sensitivity, stability and dynamic range of sensors [2, 5]. However EOMs have some disadvantages what affects the accuracy of fiber-optic sensors. A LN crystal possesses both electro-optic (Pockels) and inverse piezoelectric effects. Second one can negatively impact to stability of EOM [4]. It causes resonant mechanical oscillations in LiNbO₃ and, consequently, leads to spurious phase shift of optical radiation, which contains information about measured value. Therefore a suppression of resonant mechanical oscillations in LiNbO₃ is very important in order to use an EOM in the precision sensors.

The present paper is dedicated to the EOM based on LN crystal (x-cut) implemented by Ti diffusion technology [6] and it is considered as a part of a closed-loop fiber-optic gyroscope (FOG) for navigation grade applications. Such type of FOG was described in [7].

2. Experiment
The study was implemented in three stages.

2.1. The electrical method of the EOM study
When modulating voltage is applied to electrodes of EOM the electrical impedance of the EOM is changed because of piezoelectric effect. Thus, on the first stage the study of mechanical resonances of the EOM has been implemented by means of the measurement of electrical impedance as follows. An electrical sinusoidal signal with different frequencies is applied to the electrodes through high frequency connector and the reflected signal is estimated (S₁₁-parameter) [8]. If the frequency of the electric signal matches the frequency of natural oscillations of the EOM then energy of this signal is partially consumed for mechanical oscillations and, consequently, an amplitude of reflected signal is decreased. These measurements are implemented for two frequency ranges: 1 – 600 kHz and 300 kHz...
- 10 MHz. The \( S_{11} \)-parameter for low-frequency range was measured by set-up based on the developed electronic circuit, precision digital oscilloscope (Rohde & Schwarz, RTO1024) and arbitrary waveform generator (RIGOL DG4102). The same characteristic for high-frequency range was measured by vector network analyzer “OBZOR TR1300/1”. As a result we've received graphs which demonstrate a presence of resonant frequencies of the EOM sample.

After that we’ve fixed the EOM on the substrate by various materials in order to reduce or eliminate resonances in the EOM. Epoxy adhesive, UV curing optical adhesive, urethane adhesive, liquid sodium silicate have been used as fixing materials. The experiment results for the liquid sodium silicate are shown in figure 1.

![Figure 1](image1.png)

**Figure 1** (a, b). \( S_{11} \) parameter before and after fixing the EOM by liquid sodium silicate: (a) 1 – 600 kHz frequency range; (b) 300 kHz – 10 MHz frequency range.

### 2.2. The optical method of the EOM study

The EOM is part of the high precision fiber-optic gyroscope (FOG). Therefore, on the second stage of the research an influence of the resonant oscillations of the EOM on output signal of FOG is estimated in this paper as well. Such FOG is an interferometric sensor based on Sagnac effect. An operating principle of it is well known [5, 7]. The basic circuit of the EOM as a part of a FOG is presented in figure 2.

![Figure 2](image2.png)

**Figure 2.** The measurement circuit of the influence of mechanical resonances on interferometric signal in the FOG scheme.
As shown in figure 2 the EOM was included in FOG circuit and special modulating signal was applied to the EOM electrodes. The form of this modulating signal is meander, which peak-to-peak amplitude contributes the resulting phase shift is equal to π radians. The high precision digital oscilloscope “Rohde & Schwarz RTO1024” registered interferometric output signal with sample rate value of 5 GSa/s. The photodetector signal, which was registered by oscilloscope, is shown in figure 3, where τ corresponds to eigenfrequency (or proper frequency) of the fiber coil and depends on coil length [5]. In our case, τ is equal to 7.3 microseconds. The τsamp is time when analog-to-digital converter (ADC) operates, i.e. ADC acquisition implements during the τsamp. Signal ripple during the “τsamp” can enter distortions to the ADC signal, so it is important to reduce mechanical resonances of the EOM. The spectrum of the signal during “τsamp” is shown in figure 3 as well.

![Photodetector signal](image)

**Figure 3 (a, b).** The measurement of the interferometric FOG signal before and after fixing of the EOM by liquid sodium silicate (LSS): (a) photodetector voltage vs number of sample; (b) the spectrum of “τsamp” signal.

Experimental results show presence of intensity fluctuation of the FOG interferometric signal before fixing the EOM (figure 3, red curve). This fluctuation frequency is about 1.3 MHz that agrees with previous experiment. Suppression of resonant oscillations by means of the fixing by liquid sodium silicate significantly reduces such fluctuations of the interferometric signal.

2.3. **Noise reduction of the FOG output signal**

On the third stage we’ve measured the FOG output signal (angular velocity, see figure 2) before and after fixing of the EOM to confirm the obtained results. FOG remained stationary during the experiment, thus the measured angular rate was constant and equal to the projection of the Earth’s rate on the axis of fiber-optic coil. The signal noise level has been estimated by computing the standard deviation of FOG signal with and without fixing of the EOM. The obtained output data were averaged over 1 second. The output FOG signals for the both cases are presented in figure 4.
3. Conclusion

Influence of natural resonant oscillations on operation of the electro-optic modulator based on lithium niobate was experimentally revealed. Such behaviour of EOM is explained by piezoelectric effect which result in change of waveguide and polarization parameters of EOM and result in change of electro-optic coefficients of the crystal as well. The fixing of EOM on the substrate by various materials was implemented to reduce the noise of a fiber-optic gyroscope. Thus, we’ve demonstrated efficiency of this method for noise reduction of fiber-optic sensors. In particular, fixing of the EOM on the substrate by liquid sodium silicate has led to decrease of standard deviation of the output FOG signal by 3.7 times.

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