Journal of Physics: Conference Series **735** (2016) 012040 doi:10.1088/1742-6596/735/1/012040

An investigation of the influence of residual amplitude modulation in phase electro-optic modulator on the signal of fiber-optic gyroscope

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Abstract. The investigation is devoted to residual amplitude modulation (RAM) of phase electro-optic modulator, which guides are made in $LiNbO_3$ crystal by Ti diffusion technology. An analysis is presented that shows influence of RAM on the signal of fiber-optic gyroscope. The RAM compensation method is offered.

1. Introduction

The principle of fiber-optic gyroscope (FOG) is based on Sagnac effect. Two beams from a laser are injected into the same fiber but in opposite directions. Due to the Sagnac effect, the beam travelling against the rotation experiences a slightly shorter path delay than the other beam [1]. The resulting differential phase shift is measured through interferometry, and it is proportional to the angular velocity.

A minimal configuration of FOG [2] is presented in Figure 1.

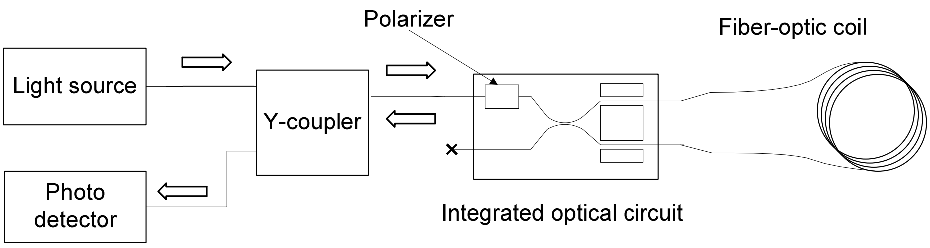

Figure 1. FOG minimal configuration.

When the optic system is rotating in inertial space with angular velocity Ω, differential phase shift is expressed as:

$$\Delta\varphi_r = (2\pi LD / \lambda_0 c)\Omega,$$

where: λ_0 – the wavelength of light in vacuum, D – the diameter of fiber-optic coil, L – the length of optic fiber, Ω – the detected angular velocity [3].

The intensity of the output signal of the interferometer is changing by cosine law depending on phase difference $\Delta\varphi_r$, defined by angular velocity:

$$I(\Delta\varphi_r) = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos(\Delta\varphi_r),$$

where I_1 and I_2 – intensities of the interfering waves.

In order to achieve a higher sensitivity the signal is shifted by the phase modulator in the operating point where $I(\Delta\varphi)$ is maximal. Then the signal of the interference is expressed as:

$$I(\Delta\varphi_r) = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos(\Delta\varphi_m + \Delta\varphi_r), \quad (1)$$

where $\Delta\varphi_m$ – the phase shift, provided by phase modulator.

One of the most widespread methods of maintaining the operating point to quadrature is using of an electro-optic phase modulator. The most often used electro-optic phase modulators are modulators on $LiNbO_3$ crystal because of high linearity of the electro-optic effect and high operation speed.

But $LiNbO_3$ phase modulators have a significant shortcoming, which is expressed in residual amplitude modulation (RAM). As a result a light beam receives both phase shift and intensity changes [4]. As RAM magnitude increases so the phase shift provided by modulator becomes less well defined [5]. So lower accuracy of fiber-optic interferometry sensors is a consequence of RAM. Therefore it is necessary to reduce RAM for increasing FOG accuracy.

2. RAM measures

RAM is evaluated by coefficient which is expressed as:

$$k_{RAM} = \Delta I / I_m,$$

where: ΔI – the magnitude of oscillation of interferometry signal caused by RAM, I_m – the medium value of signal intensity without modulation.

The integrated optical circuit made in $LiNbO_3$ crystal by Ti diffusion technology is presented in Figure 2.

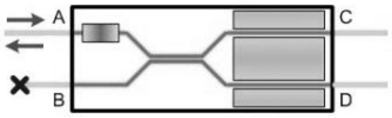

Figure 2. Integrated optical circuit.

The integrated optical circuit consists of the integrated optical polarizer in the arm A, X-splitter and the electro-optic phase modulator with three electrodes. After the polarizer the light beam is divided on two similar beams by X-splitter and propagates to phase modulator where the phase of both beams is modulated.

The $k_{RAM}(U)$ has been measured by the next way: the voltage has been applied to electrodes of the phase modulator, and output signals of each arm (C and D) have been detected synchronously with the applying voltage. The resulting RAM coefficients in the upper arm of modulator $k^U_{RAM}(U)$ and lower one $k^L_{RAM}(U)$ are shown in Figure 3.

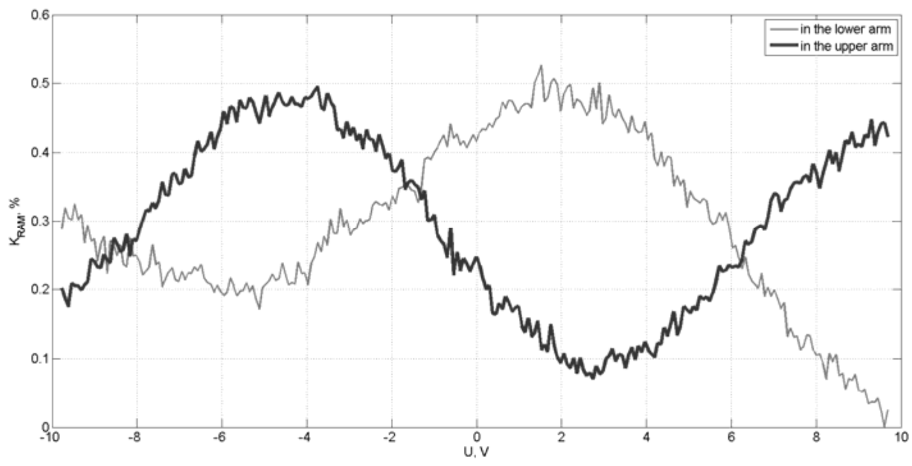

Figure 3. RAM coefficient dependence on applied voltage.

3. RAM influence on FOG signal

Measured $k^{U}_{RAM}(U)$ and $k^{L}_{RAM}(U)$ were entered in the program model of the FOG signal processing. Taking the RAM into account the intensities of two interfering beams from equation (1):

$$I_1 = \frac{I_0}{2}\left[1 - k^{U}_{RAM}(U_1)\right]\left[1 - k^{L}_{RAM}(U_2)\right], \quad (2)$$

$$I_2 = \frac{I_0}{2}\left[1 - k^{L}_{RAM}(U_1)\right]\left[1 - k^{U}_{RAM}(U_2)\right]. \quad (3)$$

where I_0 - the intensity of optical radiance of interfering waves.

In order to simplify the next text it is suggested to enter the replacement:

$$k_U(U) = 1 - k^{U}_{\mathrm{RAM}}(U),$$

$$k_L(U) = 1 - k^{L}_{RAM}(U).$$

Then equation (2) and equation (3) are expressed as:

$$I_1 = \frac{I_0}{2} k_U(U_1) k_L(U_2),$$

$$I_2 = \frac{I_0}{2} k_L(U_1) k_U(U_2).$$

In order to describe the influence of RAM on the FOG signal it is suggested to consider the differential signal of photo detector which is using for forming the signal of angular velocity:

$$\Delta I = I - I_{pr},$$

where: I – the current signal of photo detector, I_{pr} – the previous signal of photo detector.

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos(\Delta\varphi) = \frac{I_0}{2}[k_U(U_1)k_L(U_2) + k_L(U_1)k_U(U_2)]$$
$$+ I_0\sqrt{k_U(U_1)k_L(U_2)k_L(U_1)k_U(U_2)}\cos(\Delta\varphi),$$

$$I_{pr} = I_{1pr} + I_{2pr} + 2\sqrt{I_{1pr} I_{2pr}}\cos(\Delta\varphi_{pr}) = \frac{I_0}{2}[k_U(U_2)k_L(U_3) + k_L(U_2)k_U(U_3)]$$
$$+ I_0\sqrt{k_U(U_2)k_L(U_3)k_L(U_2)k_U(U_3)}\cos(\Delta\varphi_{pr}).$$

We use the FOG signal processing method based on quadrature modulation with a feedback loop which compensates the phase shift provided by the angular velocity [3]. In case when the feedback compensates the phase shift completely, the resulting phase shift under the cosine function is π/2 and $\cos(\pi/2) = 0$. So it is possible to neglect the second term of the expression for the intensity of output signal of the photo detector. Then the differential signal of the photo detector is expressed as:

$$\Delta I = I - I_{pr} = \frac{I_0}{2}[k_U(U_1)k_L(U_2) + k_L(U_1)k_U(U_2) - k_U(U_2)k_L(U_3) - k_L(U_2)k_U(U_3)]$$
$$= \frac{I_0}{2}\{k_L(U_2)[k_U(U_1) - k_U(U_3)] + k_U(U_2)[k_L(U_1) - k_L(U_3)]\}. \quad (4)$$

Due to equation (4) the error in the differential signal of the photo detector is conditioned by the difference of amplitude coefficients $k_U(U_1)$ and $k_U(U_3)$, and $k_L(U_1)$ and $k_L(U_3)$. Consequently the error of the FOG output signal depends on the slope of $k_U(U)$ and $k_L(U)$.

4. RAM compensation method

There is offered an algorithmic method of compensation of the RAM influence on the FOG signal. It is possible to adjust the signal of the photo detector on the correction factor. In case when the feedback compensates the phase shift provided by the angular velocity completely, the output signal of the photodetector can be expressed as:

$$I = I_1 + I_2 = (I_0/2) \cdot [k_U(U_1)k_L(U_2) + k_L(U_1)k_U(U_2)]. \quad (5)$$

Due to equation (5) the adjusted signal of the photodetector is expressed as:

$$I' = 2I \cdot [k_U(U_1)k_L(U_2) + k_L(U_1)k_U(U_2)]^{-1}.$$

This method of the signal adjusting was added into the program model of the FOG signal processing. The comparison of the FOG output signal with averaging over 1 sec of algorithm with the RAM compensation method and without it was made by computer simulation. Results are presented in Figure 4.

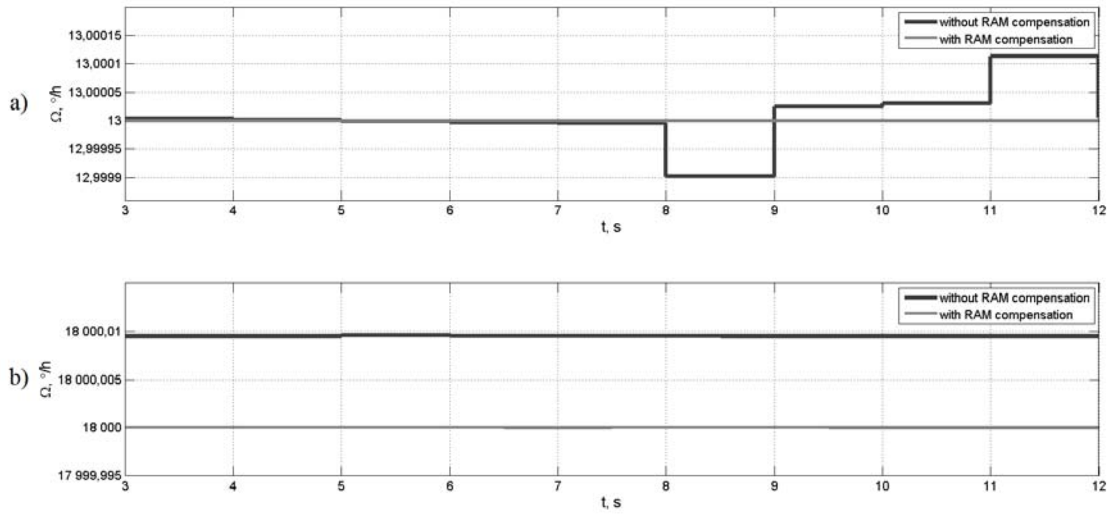

Figure 4. Computer simulation. The comparison of the FOG output signal of algorithm with the RAM compensation method and without it: a) in case the angular velocity is 13 °/h, b) in case the angular velocity is 18000 °/h.

The comparison of algorithms shows that described RAM compensation method promotes a decreasing of the standard deviation and promotes a decreasing of signal`s bias in case of high angular velocities.

5. Conclusion

This paper is devoted to investigation of residual amplitude modulation (RAM) of phase electro-optic modulator, which guides are made in $LiNbO_3$ crystal by Ti diffusion technology. The investigation shows that RAM promotes increasing of standard deviation and bias of the FOG`s output signal. The RAM compensation method, offered in the paper, allows to decrease the angular rate signal`s standard deviation and bias.

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