Frequency Modulate Laser Based Interferometric Optical Gyroscope

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Abstract: We report the performance of a high-speed frequency modulated laser based interferometric optical gyroscope. The motivation lies in the advantages of a laser based system enabled on advanced integrated optics. We demonstrate that this approach improves both angular random walk and bias stability.

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1. Introduction and motivation

The fiber optic gyroscope has become, arguably, the most commercially successful optical sensor to date [1]. Historically, the first laboratory experiments involving interferometric fiber optical gyroscopes (IFOG) utilized a laser as the source [2], however the coherence length led to poor performance and modulation was needed to de-cohere the source. The problem at the time was the large V_π of $LiNbO_3$ modulators and use of traveling wave electrodes to set the required source coherence length that led to unacceptable signal distortion (harmonics) and power dissipation. The sudden availability of erbium doped fiber ASE sources led researchers to quickly adapt the ASE source to meet these requirements. Employing a source with a short coherence length significantly suppresses the interference between various parasitic waves generated in the system due to back-reflection, backscattering and Kerr nonlinearity, which in turn leads to reduced noise and improved system performance [3]. IFOGs have therefore generally utilized superluminescent diodes (SLED) or Erbium-doped fiber (EDF) based sources [3, 4]. EDF based sources generally offer the best performance, but at the same time are more costly and harder to package. Recently, the use of single-frequency lasers with high-spectral purity has been considered as an alternative to broadband sources [5]. A single-frequency laser source does not suffer from excess noise and thus can achieve a higher scale factor stability. In [5], the authors show that through a careful selection of laser coherence (narrow-linewidth) and adoption of a push-pull phase modulation technique (common in most modern IFOG setups), a better (lower) angle random walk can be achieved, although, at the expense of a higher drift (bias instability).

In this work, we explore the use of high-speed frequency modulated lasers in interferometric optical gyroscopes. Our primary motivation in doing so results from our vision of realizing full chip-scale integration of an interferometric optical gyroscope where the active optical components on heterogeneous integrated Si platform would be interrogated with an integrated sensing coil realized in ultra-low loss Si_3N_4 waveguides [6, 7]. Integration of all components and propagation of a fixed polarization on chip using polarization preserving waveguides and delays eliminates many of the bulk optic assembly issues related to polarization maintaining components as well as reduced performance due to polarization misalignment under environmental and aging stress factors. We have presented preliminary results obtained with an integrated 3 meter long Si_3N_4 waveguide coil [8]. However, on a chip-scale platform, broadband circulators as well as isolators are not readily available; our integrated optical gyroscope architecture is therefore based on a coupler configuration [7]. In such an architecture, approximately half of the received signal is fed back into the optical source; thus, both erbium and III-V based broadband sources would either lase or emit most of their output power in the back direction. A laser, with a resonant cavity, allows us to control the direction of lasing output through proper mirror design and this is an area of ongoing research.

To date, frequency modulation of a laser source in conjunction with an optical gyroscope, to the best of our knowledge, has received relatively little published attention. Cutler et al. suggested that a fast change in source frequency can reduce the errors due to Rayleigh scattering [9]. Culshaw et al. investigated heterodyne detection of FM modulated laser light in an IFOG primarily to overcome 1/f noise problems [10]. More recently, Blin et al. investigated the use of frequency modulated lasers in IFOGs and concluded that sweeping of the laser source frequency can reduce backscatter noise [11]. Unfortunately, [11] did not include a comparison between swept laser source frequency and key gyroscope performance indicators such as angular random walk or bias stability. Here, we report the performance of our interferometric optical gyroscope utilizing a directly modulated FP laser above threshold. We show that with proper modulation, both the angular random walk and bias stability can be significantly enhanced.

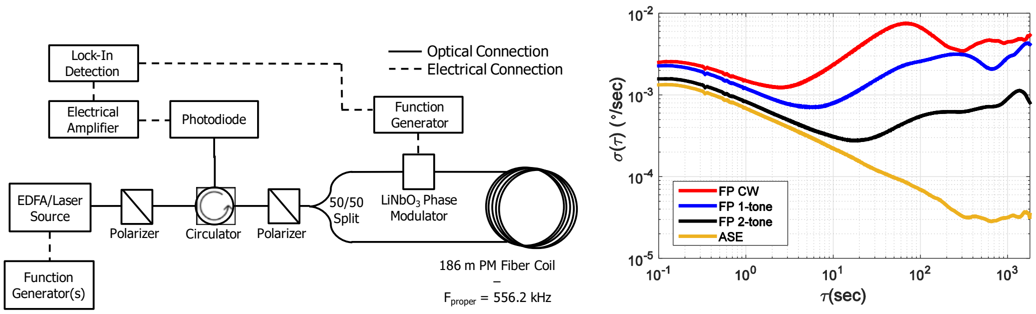

Fig. 1. (left) Schematic of in-house assembled fiber-based optical gyroscope. All fibers after the first polarizer are PM and input polarization is optimized for maximum power at the photodiode. Components are connected with FC/APC connectors. (right) Allan deviation measurements for an FP laser at CW, single, and two-tone modulation compared to an ASE source.

2. Characterization of the frequency modulated laser based interferometric optical gyroscopes

We built an in-house assembled discrete fiber-based optical gyroscope to evaluate the performance with the FP laser at continuous wave, single and two tone modulation compared to an ASE source. We implemented a simplified configuration shown in Figure 1-left, containing a single commercial $LiNbO_3$-based phase modulator and a 186 m long PM fiber coil with a diameter of 30 cm. The entire setup was placed on a rotation table to perform the scale factor measurement. Measurements of Allan deviation were then performed over a period of one hour, with the results plotted in Figure 1-right. The output voltage of the gyroscope was converted to rotation rate °/s using the acquired scale factor measurement. The values of angle random walk and bias instability are presented in Table 1.

	FP CW	FP 1-tone FM	FP 2-tone FM	ASE
Angle random walk (°/√hr)	0.090	0.072	0.050	0.041
Bias instability (°/hr)	4.480	2.576	1.015	0.102

Table 1. Values of angle random walk and bias instability read out from the Allan deviation plot in Fig. 1.

The measurement results clearly indicate that the frequency modulation of an FP laser can largely improve both the angular random walk and bias drift, as compared to the continuous wave (CW) case. In fact, the angle random walk of the laser-based gyroscope was reduced significantly enough that it closely approached the level of the ASE-driven configuration. Bias drift, although significantly improved with modulation, remains relatively high. We expect that splicing the connectors would further improve the performance, as would employing a push-pull modulation scheme [5]. Note that a fully-integrated chip-scale optical gyroscope should be more stable in terms of temperature and polarization drift, compared to this discrete fiber implementation. The improvement in performance due to the applied modulation can be properly explained by the optical source coherence functions as will be shown in detail at the conference.

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