

Evidence-Driven Design of a Silicon-Photonic Transceiver for an Interferometric Fiber-Optic Gyroscope

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Abstract: We report on an experiment-driven design of a silicon-photonic gyroscope transceiver, deriving integration constraints from a characterized prototype. Measurements yield $0.048^\circ/\text{h}$ bias instability and $0.021^\circ/\sqrt{\text{h}}$ angle random walk, guiding on-chip implementation.

1. Introduction

Interferometric fiber-optic gyroscopes (IFOGs) are widely used in inertial navigation because their reciprocal interferometric architecture supports low drift and long-term bias stability. Their main limitation is SWaP [1]: conventional implementations rely on discrete fiber components and packaged electro-optic devices, limiting adoption in small spacecraft and compact platforms. MEMS and integrated resonant gyroscopes offer compelling miniaturization, yet sustaining navigation-grade bias stability remains challenging. Recent advances in silicon photonics and photonic integrated circuits (PICs) [2] enable dense integration of interferometric building blocks on wafer-scale processes, improving manufacturability.

This paper reports on an experiment-driven design flow for a silicon-photonic gyroscope transceiver. We first integrate a one-axis interferometric gyroscope using only commercially available (COTS) components and experimentally characterize its optical readout chain under static and controlled rotational conditions. The measured insertion-loss budget, polarization handling, modulation requirements, and receiver-noise limits are then propagated down into the design of a PIC that integrates the polarizer, reciprocal splitters/combiners, phase modulation, and photodetection. The broadband source and the fiber coil remain off-chip. By basing the PIC design on experimental evidence, the proposed transceiver provides a concrete path from laboratory prototype to compact, foundry-compatible mini-IFOGs.

2. Prototype

A C-band superluminescent diode (50 nm bandwidth, 21 mW max power) provides low-coherence illumination; the launched power is set through a variable optical attenuator. A low-loss three-port circulator routes the emission to a lithium-niobate multifunction integrated optical circuit (MIOC). The MIOC integrates a polarizer, a Y-junction splitter/combiner, and a push-pull phase modulator ($V_\pi = 4 \text{ V}$). The sensing element is a 500 m polarization-maintaining (PM) fiber coil wound on an 80 mm inner-diameter spool. After recombination, the returning interference signal is directed by the circulator to an InGaAs photodiode followed by a broadband transimpedance amplifier. A modular layout with connectors and a 3D-printed enclosure enabled iterative reconfiguration and controlled rotation tests. This modular packaging trades SWaP for accessibility, clarifying the benefit of integration.

Characterization has been performed under static and rotational conditions. A 24 h zero-rate record of the lock-in output was analyzed using Allan variance to estimate the bias instability and angular random walk, while rate-table sweeps from $-10^\circ/\text{s}$ to $10^\circ/\text{s}$ (in $1^\circ/\text{s}$ steps) were performed to verify linearity. The measured Allan variance is shown in Fig. 1. The bias instability is $0.048^\circ/\text{h}$, the angle random walk is $0.021^\circ/\sqrt{\text{h}}$ [3,4]. Crucially, the measured optical power budget, polarization management, modulator drive, and receiver noise have been converted into constraints for the silicon-photonic transceiver, motivating on-chip polarization filtering, reciprocal splitting/combination, phase modulation, and photodetection.

3. Silicon Photonic Integrated Circuit

The PIC integrates all optical functions of a single-axis interferometric fiber-optic gyroscope except for the broadband SLED and the external polarization-maintaining fiber coil. The layout of the designed silicon photonic chip occupies a $5.15 \times 5.15 \text{ mm}^2$ die and includes eight configuration variants and test structures. In the main configuration, three grating couplers provide the external interfaces: one injects broadband light into the circuit and two connect to the opposite ends of the PM coil, reproducing reciprocal counter-propagation. The grating-coupler array is arranged for fiber-array packaging. Broadband 1×2 and 2×2 multi-mode interference (MMI) couplers implement splitting and recombination with high symmetry.

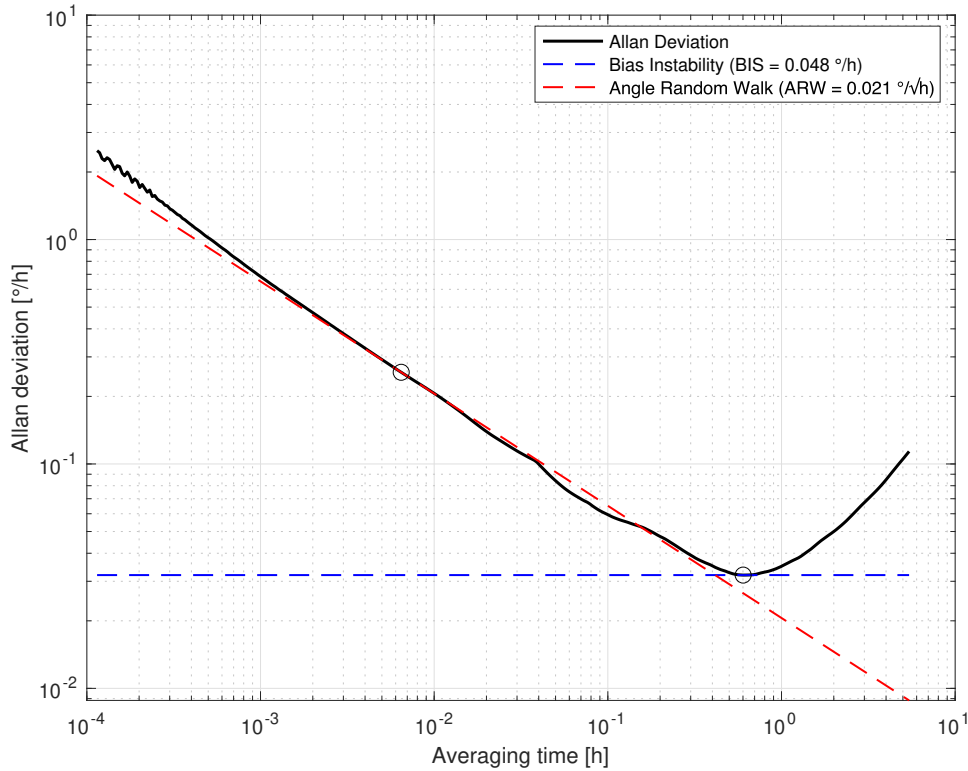


Fig. 1. Allan deviation plot of the FOG prototype.

Prototype-based experiments have triggered the most innovative aspect of the PIC design. Polarization is stabilized by combining TE-selective grating couplers with a shallow-etched rib-waveguide polarizer that strongly attenuates TM through lateral leakage, reducing polarization-coupling noise in the external coil [5]. Phase modulation is implemented through a pure-phase modulator based on a Mach-Zehnder interferometer with tunable couplers and a plasma-dispersion phase shifter; adjustable bias points suppress residual amplitude modulation (RAM) and mitigate spurious bias in interferometric readout [6]. The interference signal is converted by germanium photodiodes, with an optional balanced configuration for common-mode rejection, while the photocurrent is delivered to an external transimpedance amplifier consistent with the validated analog front-end.

4. Conclusions

We demonstrate an evidence-driven design methodology that maps experimentally validated COTS interferometric FOG performance into a foundry-ready silicon-photonics transceiver integrating polarization filtering, reciprocal splitting/combination, push-pull phase modulation, and Ge photodetection, while keeping only the broadband source and PM fiber coil off-chip. This prototype-to-PIC flow provides a concrete path to chip-scale mini-IFOGs; forthcoming fabrication and measurements will verify bias drift and noise preservation and quantify the achievable SWaP reduction.

References

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