

Interferometric Fiber Optic Gyroscope: Principle of Operation and Basic Parameters Determination

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The presented method, based on the theory and equations of fiber optic gyroscope, gives a possibility to select appropriate interferometric fiber optic gyroscope (IFOG) parameters and components to satisfy measuring range, bias, noise, etc. It is thus possible to realize software and hardware of appropriate IFOG.

Key words: gyroscope, fiber optic gyroscope, open loop, closed loop, phase modulation.

Introduction

DESIGNING of an IFOG requires a good theoretical understanding of the principles as well as the knowledge of components and technology used for gyro production. This work summarizes both theoretical requirements and technology possibilities for gyro design.

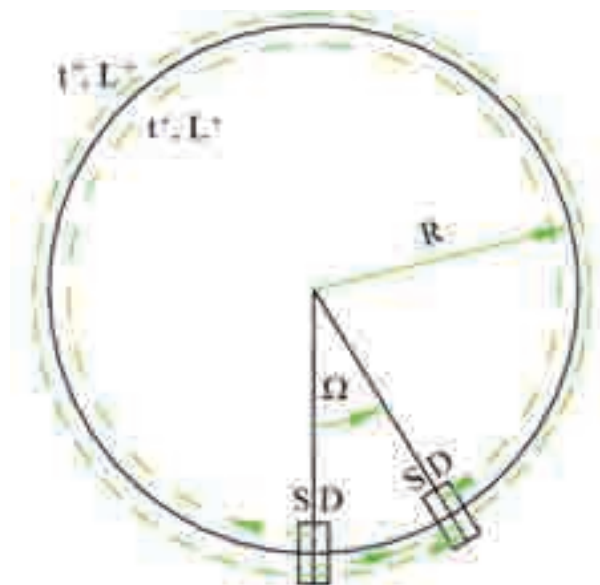


Figure 1. Transient time difference due to rotation

In applications where a gyro drift between 0.001 deg/h and 1deg/h is required, IFOG successfully displaced the ring laser gyroscopes (RLG). These applications are in strapdown inertial system navigation for stabilization applications, tactical missiles, land vehicles, aircraft AHRS and inertial navigation systems (INS), strategic missiles, etc. [5]. In comparison with MEMS gyroscopes, they are more precise, while they are lighter and smaller than RLG, have longer life and are more rugged.

The IFOG is an interferometric fiber optic gyroscope. The function of this gyro is based on the "Sagnac" effect [1]. The Sagnac's fringe shift is present in the rotating ring

interferometer, Fig.1 when two light beams circulate in opposite directions

The light source S is a light emitter of two waves traveling in opposite directions around a path of radius R. The light source and the detector D are rotating with angular velocity Ω , so that a light beam traveling in the rotating direction travels a longer distance L^+ for longer time t^+ while the opposite light beam travels a shorter distance L^- for shorter time t^- .

Then

$$L^+ = 2\pi R + R\Omega t^+ \quad (1)$$

$$L^- = 2\pi R - R\Omega t^- \quad (2)$$

The light speed in the medium is:

$$c_m = \frac{c}{n} \quad (3)$$

where:

c - light speed in vacuum

c_m - light speed in a particular medium

n - index of refraction in a particular medium

If $n \sim 1$, $c_m \sim c$, then:

$$t^+ = \frac{L^+}{c} \quad (4)$$

$$t^- = \frac{L^-}{c} \quad (5)$$

The substitution of (4) and (5) into (1) and (2) yields:

$$L^+ = \frac{2R\pi}{1 - \frac{R\Omega}{c}} \quad (6)$$

$$L^- = \frac{2R\pi}{1 + \frac{R\Omega}{c}} \quad (7)$$

From (6) and (7) it is obtained:

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$$\Delta L = L^+ - L^- = \frac{4R\pi \frac{R\Omega}{c}}{1 - \frac{R^2\Omega^2}{c^2}} \approx \frac{4R^2\pi\Omega}{c} \quad (8)$$

$$\Delta t = \frac{\Delta L}{c} = \frac{4R^2\pi\Omega}{c^2} \quad (9)$$

If the waves can circle the path N times:

$$\Delta L = \frac{4NR^2\pi\Omega}{c} = \frac{4NA}{c}\Omega = \frac{LD}{c}\Omega \quad (10)$$

$$\Delta t = \frac{4NR^2\pi\Omega}{c^2} = \frac{4NA}{c^2}\Omega \quad (11)$$

Where:

A – area enclosed by path

D – path diameter

L – total length traversed

For a wave of frequency f (wavelength $\lambda=c/f$), the period $T=1/f$ is time taken for a 2π phase change, so that the Sagnac phase change Φ over time Δt is:

$$\Phi = 2\pi \frac{\Delta t}{T} = 2\pi f \Delta t \quad (12)$$

so that, after substituting for Δt in (12) with (10) it is:

$$\Phi = \frac{8\pi AN}{\lambda c} \Omega \quad (13)$$

The fringe shift x is then:

$$x = \frac{\Phi}{2\pi} \quad (14)$$

$$x = \frac{4AN}{\lambda c} \Omega = \frac{4DL}{\lambda c} \Omega = K_0 \Omega \quad (15)$$

where, K_0 is the open-loop scale factor. The light path can be defined by prisms (Hares), mirrors (Sagnac), or optical waveguides. It can have any shape, and A is the plan area of the shape normal to the rotation vector.

“SAGNAC” sensitivity

Assume a lossless Sagnac interferometer with an ideal 3-db beam splitter. The light amplitude at the detector is the sum of the clockwise and counterclockwise amplitudes, shifted by Sagnac phase Φ .

$$E_D = E^+ e^{j0} + E^- e^{-j\Phi}$$

Assuming that the amplitudes are identical

$$E^+ = E^- = E$$

Then:

$$\begin{aligned} E_D &= E(\cos 0 + j \sin 0 + \cos \Phi - j \sin \Phi) = \\ &= E(1 + \cos \Phi - j \sin \Phi) \end{aligned}$$

The intensity on the detector is

$$I_D = |E_D|^2 = 2|E|^2 (1 + \cos \Phi) = 2I(1 + \cos \Phi)$$

where $I = |E|^2$

The sensitivity is

$$|dI/d\Phi| = 2I \sin \Phi$$

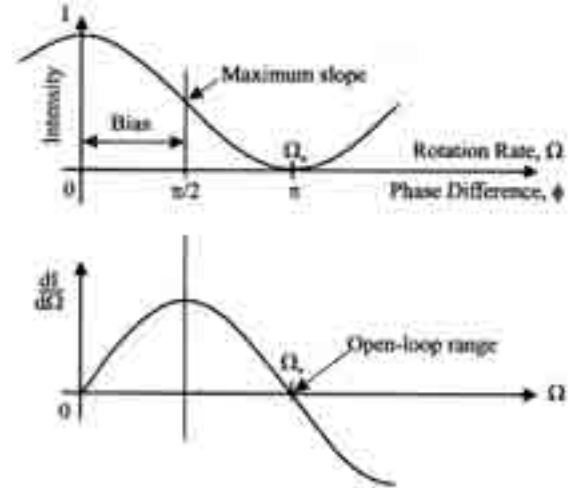


Figure 2. Sagnac interferometer sensitivity

As seen in Fig. 2, the minimum value of sensitivity is at no rotation when the phase shift is zero and at the maximum value when the phase shift is π . Under these conditions the threshold has the minimum value.

If the interferometer is stationary in inertial space, the maximum intensity is at the detector. As the interferometer rotates faster the intensity drops, reaching zero when the Sagnac phase difference is π . The maximum angular rate for the phase difference π is obtained from (13):

$$\Omega = \frac{\Phi \lambda c}{8\pi AN} = \frac{\pi \lambda c}{8\pi AN} = \frac{\lambda c}{8AN} \quad (16)$$

To improve gyro sensitivity, the interferometer can be biased to the point of the maximum slope at $\Phi = \pi/2$. In this case the maximum sensitivity of the open loop gyro is at low angular rates. Maximum angular rate range is limited to that which represents a $\pm \pi/2$ phase shift.

$$\Omega_{\max} = \pm \frac{\lambda c}{16AN} \quad (17)$$

For example, if the coil diameter is a 100 mm, number of turns is $N = 1000$ ($L \approx 314$ m) and the light source wavelength is $\lambda = 1550$ nm then:

$$\Omega_{\max} \approx \pm 3.7 \text{ rad/s} \approx \pm 212^\circ/\text{s}$$

The gyro characteristic in the open loop is not linear, i.e. the scale factor is not linear and depends on the phase shift as represented in Fig.2.

To overcome the open loop gyro problem, a servo loop is closed on the Sagnac phase, inserting a phase modulator to oppose it so that the output intensity stays at the maximum-slope bias point.

The fundamental limit of IFOG performance

There are two noise sources to consider for the IFOG:

- the photon shot noise
- the relative intensity noise

Photon shot noise

While optical gyros have excellent stability over periods of hours, they are quite noisy in the short term (over seconds); indeed, they act as white noisy generators. Their

theoretical fundamental threshold noise really does set a lower limit of their performance.

Light energy is quantized in photons, and when light falls on a detector, it creates electrical noise (photon shot noise). Assuming that the detector amplifier electronic noise is small, the shot noise depends on the detector current and the measuring bandwidth [1], its r.m.s value being

$$i_s = \sqrt{2ei_d B} = \sqrt{\frac{ei_d}{t_s}} \quad (18)$$

where:

e – electron charge

i_d – average detector current

B – measurement bandwidth $B = \frac{1}{2t_s}$

t_s – sample time

The gyro scale factor K is the ratio of the output signal (average detector current) to the input angular rate.

$$K = \frac{i_d}{\Omega} \left[\frac{A}{\text{rad/s}} \right]$$

The minimum detectable rate change, $d\Omega$, caused by the uncertainty in output current i_s , defines the resolution

$$\frac{d\Omega}{\Omega} = \frac{1}{K} \frac{di_d}{i_d} = \frac{1}{K} \frac{i_s}{i_d} = \frac{1}{K} \sqrt{\left(\frac{e}{i_d t_s} \right)} \left[\frac{\text{rad/s}}{A} \right] \quad (19)$$

If the rate noise has a white spectrum with an r.m.s. value σ , it gives rise to a random walk angle, R_θ , which propagates as the square root of time (Angle Random Walk – ARW)

$$ARW = R_\theta = \sigma\sqrt{t} \quad (20)$$

ARW is a commonly specified parameter for optical gyros.

Davis and Ezekiel [1] show that the minimum detectable rotation rate (threshold) is:

$$\Delta\Omega = \frac{2}{K_0 \sqrt{n_{ph} \eta t}} \quad (21)$$

where:

n_{ph} – number of photons/second falling on the detector

η – detector quantum efficiency

t – averaging time

K_0 – open loop scale factor

Detector quantum efficiency is defined as the number of electrons emitted per photon on the detector. In that case the current in photo detector is $n_{ph}\eta e$, where e is the electron charge. The detector is more usually characterized by the responsivity, R , and the power at the detector, P_d , is usually expressed in Watts. Accordingly

$$n_{ph}\eta e = P_d R$$

and (21) can be written:

$$\Delta\Omega = \frac{2}{K_0} \sqrt{\left(\frac{e}{P_d R t} \right)} \quad (22)$$

Based on (22) it is possible to calculate the expected IFOG threshold. If the same coil used in the previous example is considered, of diameter $D = 100$ mm, number of turns $N = 1000$ ($L \approx 314$ m) and light source with wavelength $\lambda = 1550$ nm, assuming the power at the

detector $P_d = 100$ μ W and responsivity 0,5 A/W, sample rate $t = 1$ s, then:

$$K_0 = \frac{4DL}{\lambda c} = \frac{4 \cdot 0.1 \cdot 314}{1.55 \cdot 10^{-6} \cdot 3 \cdot 10^8} = 0.027$$

$$\Delta\Omega = \frac{2}{0.027} \sqrt{\frac{1.6 \cdot 10^{-19}}{100 \cdot 10^{-6} \cdot 0.5 \cdot 1}} = 4.19 \cdot 10^{-7} \text{ rad/s} = 0.086^\circ/\text{h}$$

which is a characteristic of medium class gyroscopes for heading and attitude reference system applications.

Relative intensity noise (RIN)

In the low-coherence (broad linewidth) source the spontaneous emission gives rise to many wavelengths beating against one another, causing intensity noise. Because the coherence time is much less than the transit time around the coil, the source noise cannot be subtracted from the Sagnac signal at the detector, as it can in resonant gyros with high-coherence sources.

Fig.3 illustrates how intensity noise passes to the detector. During bias periods a , and b , the noise in the detector output is uncorrelated and the noise level in Equation (22) increases by the right-hand term:

$$\Delta\Omega = \frac{2}{K_0} \sqrt{\left(\frac{e}{P_d R t} \right) + \frac{\lambda^2}{4c\Gamma t}}$$

where λ is wavelength, Γ is linewidth (half intensity spectral width).

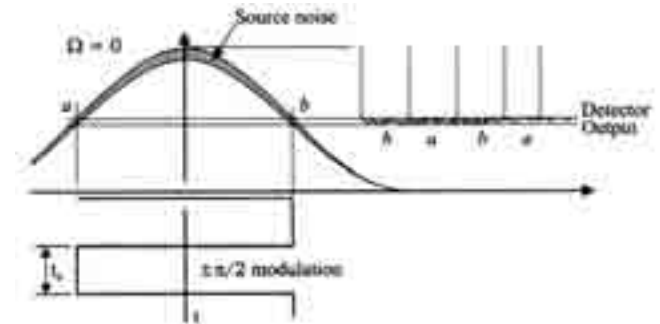


Figure 3. Relative intensity noise propagation

The shot noise dominates if the detector power is low. For high power and large linewidth the intensity noise dominates.

If we consider a gyro with $\Gamma = 50$ nm, then the previously calculated noise increases and:

$$\Delta\Omega = \frac{2}{0.027} \sqrt{\frac{1.6 \cdot 10^{-19}}{100 \cdot 10^{-6} \cdot 0.5 \cdot 1} + \frac{(1.55 \cdot 10^{-6})^2}{4 \cdot 3 \cdot 10^8 \cdot 50 \cdot 10^{-9} \cdot 1}} = 15.4 \cdot 10^{-7} \frac{\text{rad}}{\text{s}} = 0.318 \frac{^\circ}{\text{h}}$$

The relative intensity noise is greater than the shot noise, increasing it for 0.155°/h and contributing to a significant threshold increase.

“SINGLE-MODE” and “MULTIMODE” optical fiber

Fiber optics (optical fibers) are long, thin strands of very pure glass which consists of higher refractive index core and lower refractive index cladding. Core and cladding are

inside one or more layers of coating, Fig.4. Glass is formed of silicon dioxide (SiO_2) and germanium dioxide (GeO_2).

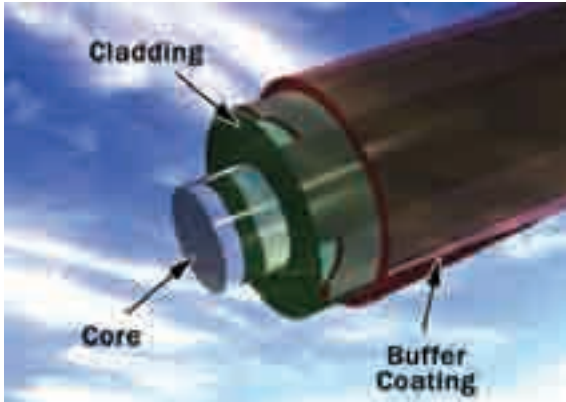


Figure 4. Optical fiber

The core is optical waveguide; the cladding is outer optical material surrounding the core that reflects the light back into the core. The buffer coating is plastic coating for protecting the fiber from damage and moisture.

Optical fibers come in two types: single-mode fibers (or monomode) and multimode fibers. The fiber diameter is an order of light wavelength magnitude.

A single-mode fiber with a relatively narrow core diameter (about 6 to 9 microns) will transmit only one lowest order bound mode of infrared laser light at wavelength 1300 to 1550 nanometers (Figures 5 and 6).

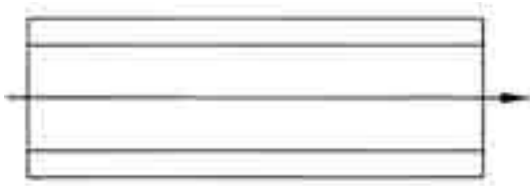


Figure 5. Monomode optical fiber propagation

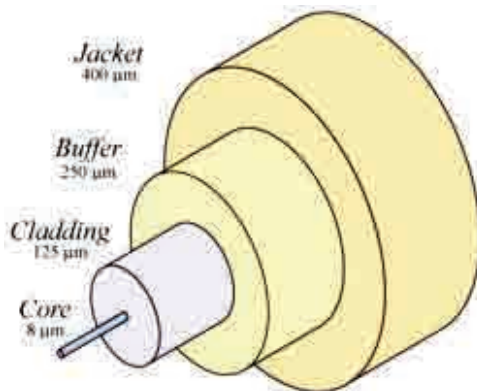


Figure 6. Monomode optical fiber structure

This type of fiber with a core diameter less than about ten times the wavelength of the propagating light cannot be modeled using geometric optics. It must be analyzed as an electromagnetic structure, by solution of Maxwell's equations as reduced to the electromagnetic wave equation. As an optical waveguide, the fiber supports one or more confined transverse modes by which light can propagate along the fiber. Fiber supporting only one mode is called single-mode or mono-mode fiber. The behavior of larger-core multimode fiber can also be modeled using the wave equation, which shows that such fiber supports more than

one mode of propagation (hence the name). The results of such modeling of multi-mode fiber approximately agree with the predictions of geometric optics, if the fiber core is large enough to support more than a few modes. Single-mode fiber carries higher bandwidth and up to 50 times more distance than multimode, but requires a light source with a narrow spectral width.

If the core is wide and there is a sharp transition between the core and the cladding, high-order rays will follow reflected paths while low-order modes will follow straighter paths. This causes some of the rays to arrive at the source at a different time—a phenomenon called modal dispersion. Dispersion limits cable distance.

The need to leave spacing between pulses to prevent overlapping limits bandwidth that is, the amount of information that can be sent. Consequently, this type of fiber is best suited for transmission over short distances (10 to 100MBS - Gigabit to 275m to 2km).

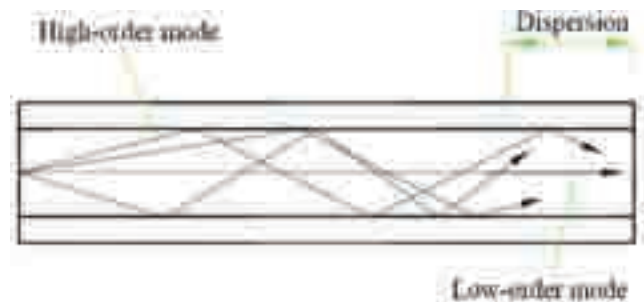


Figure 7. Step index multi-mode optical fiber

Graded-Index multimode fiber contains a core in which the refractive index diminishes gradually from the center axis out toward the cladding. The higher refractive index at the center makes the light rays moving down the axis advance more slowly than those near the cladding. Also, rather than zigzagging off the cladding, light in the core curves helically because of the graded index, reducing its travel distance. The shortened path and the higher speed allow light at the periphery to arrive at a receiver at about the same time as the slow but straight rays in the core axis. The result: a digital pulse suffers less dispersion.



Figure 8. Graded index multi-mode optical fiber

Numerical Aperture - NA

Numerical aperture (NA) is a critical performance specification for optical fibers.

NA is a unitless quantity. The numerical aperture takes into account not only the cone of acceptance, but the effect on that cone of different media outside the fiber. Let us consider the fiber with the outside media index n_0 , core index n_1 and a cladding index of $n_2 < n_1$ (Fig.9).

Maximum acceptable angle $\theta_{0\max} = \theta_{\max}$ is calculated based on critical angle at which total internal reflection occurs.

$$\theta_1 > \theta_c$$

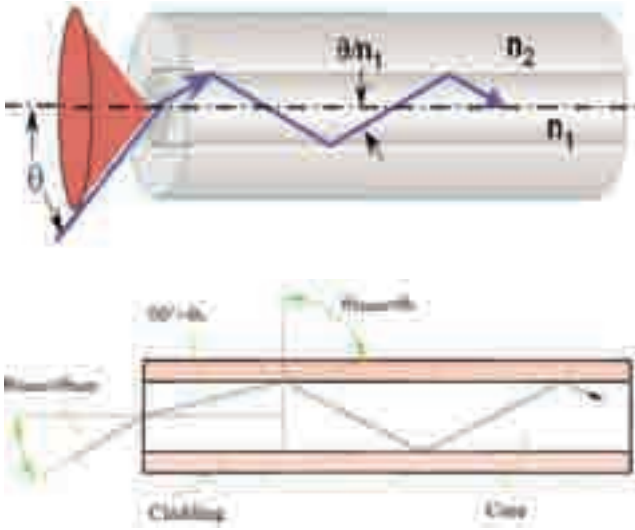


Figure 9. Numerical aperture parameters

Angle θ'_1 is complementary θ_1 :

$$\theta'_1 = 90 - \theta_1 \quad (23)$$

Snell's law of refraction applied to equation 23 gives:

$$n_0 \sin \theta_0 = n_1 \sin \theta_1 < n_1 \sin(90 - \theta_c) \quad (24)$$

therefore:

$$n_1 \sin \theta_c = n_2 \sin 90 = n_2 \quad (25)$$

Equation (25) in (24) yields:

$$n_0 \sin \theta_0 < \sqrt{n_1^2 - n_2^2} \quad (26)$$

or

$$n_0 \sin \theta_{0\max} = \sqrt{n_1^2 - n_2^2} = NA \quad (27)$$

Numerical aperture does not depend on the material outside the fiber but depends only on the indices of the core and cladding of the fiber. If the fiber is placed in a material other than air, the index n_0 will indeed increase, but the cut-off angle θ_0 will decrease to keep the product $n_0 \sin \theta_{0\max}$ constant.

Polarization

The polarization of an electromagnetic wave is defined as the direction in which the electric field propagates. A fiber drawn from a cylindrical preform has a circular cross section, so it is degenerated in polarization; there is no preferred axis for aligning polarization. But refractive index generally depends on the stress in the material, because stress causes the core to act as if it had different refractive indices in different radial directions, called stress birefringence. Therefore an actual fiber coil may provide a preferred polarization, although it may not be stable over temperature and time.

A birefringent fiber can be considered as having different propagation constants β_x and β_y along two orthogonal axes x and y normal to the fiber axis, so that the waves traveling along x and y travel at different speeds $\left(\beta = \frac{2\pi n}{\lambda_0}\right)$. Linearly polarized light coupled into

both x and y will become elliptically polarized as it moves along the fiber. When it has traveled a certain distance, the

beat length, L_b , the phase between the x and y wave components will have changed by 2π and the wave will again be linearly polarized:

$$|\beta_x - \beta_y| L_b = 2\pi$$

Another measure of fiber birefringence is the amount of power transferred between the cross-polarized states per unit length, denoted by the h -parameter. If linearly polarized light is launched into the x -axis of 1 km of a fiber with $h = \frac{1}{10^4 \text{ m}}$, 10% of the power will be in the y -axis mode at the other end.

The accuracy of FOG depends strongly on the parameters of an optical block. The gyro noise is smaller if larger is output power of light source and smaller optical losses at all optical components, including optical fiber. The minimum measured angular rate depends on polarization crosstalk h and the beat length L_b of the optical fiber as following [2]:

$$\Omega_{\min} \sim \frac{\sqrt{hL_b}}{DL} \quad (28)$$

where:

D – coil diameter

L – total fiber optic length

If we consider the same coil used in the previous examples, of diameter $D = 100$ mm, number of turns $N = 1000$ ($L \approx 314$ m) and light source with wavelength $\lambda = 1550$ nm, with $L_b = 7.8$ mm (PANDA fiber SM15-PS-U17B [4]) and $h = 10^{-5} \text{ m}^{-1}$ [2]:

$$\Omega_{\min} \sim 0.58^\circ/\text{h}$$

The reasons of polarization maintaining fiber application are:

- The accurate measurement (or nulling) of the small rotation-induced Sagnac phase requires the rejection of the large phase (e.g., $10^6 \pi$) common to the CW and CCW paths. There are two ways of ensuring this; either scramble the polarization so that it is random at the detector or ensure that the paths have identical optical lengths (identical β s). Practically, that implies that they use the same polarization [1].
- To minimize drift due to cross polarization connection
- To minimize drift due to Faraday's effect of outside magnetic fields

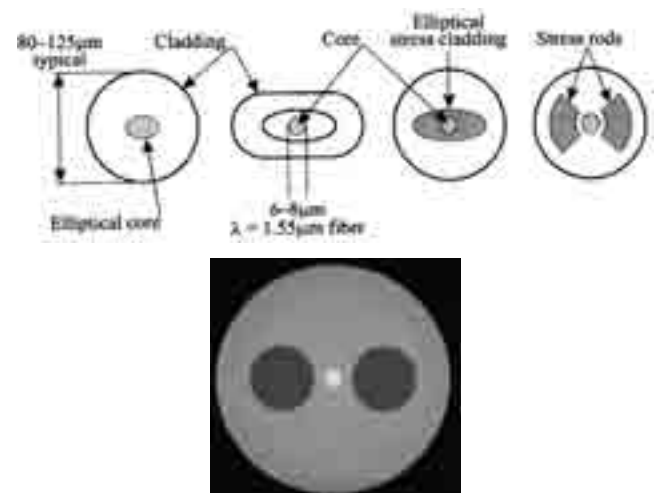


Figure 10. Some polarization maintaining fibers

Fig.10 illustrates some of the usual ways of optical fiber polarization, which are:

- Building-in an elliptical member of a different expansion glass,
- Building-in two rods (stress rods) on either side of the core—the so-called
- "Bow-Tie" fiber and the PANDA [4] fiber, for example
- Flattening the preform by squeezing it while it is hot, the so-called
- "square" fiber.

Square fiber has the useful property that the asymmetry axis is clearly visible from outside and coils with controlled core position can be readily wound. Stress rods function by setting up an asymmetric stress in the core when the fiber cools down.

Gyro closed loop

Due to gyro rotation there is a fringe shift according to equation 15:

$$x = \frac{4AN}{\lambda c} \Omega$$

This shift is equivalent to phase i.e. frequency difference thus generated. The fringe shift equivalent to the phase difference is a product of the phase difference and the coil propagation time:

$$\Delta f t_d = \Delta f \frac{nL}{c} = \frac{4AN}{\lambda c} \Omega \quad (29)$$

i.e.

$$\Delta f = \frac{D}{n\lambda} \Omega = K \Omega \quad (30)$$

The "Sagnac" path difference can be nulled by changing the frequency of the light circulating in one direction around the coil.

The phase nulled gyro scale factor is:

$$K = \frac{D}{n\lambda} \quad (31)$$

For loop closing, most of producers use the phase integrated optical chip modulator, Fig.11.

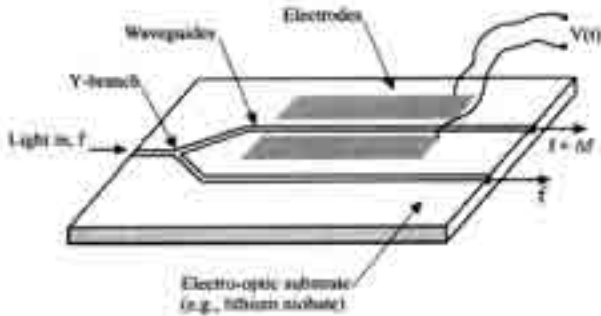


Figure 11. An optical chip modulator

The modulator is an active electro-optic crystal. Lithium niobate is most often used. Waveguides are made in lithium niobate by diffusing titanium into the surface of the crystal in stripes 3-6 μm wide and deep; these in-diffused regions have the higher index needed for them to act as waveguides.

The electro-optic effect in lithium niobate used to change the guide's effective index by applying an electric field transversely across the guide. The transverse field comes

from electrodes deposited on the substrate, and the propagation constant β in the guide interacting with the field is proportional to the voltage. In such way a phase shift is introduced to an optical signal. Integrated optics involves the processing of light waves by modulators, switches, and amplifiers.

Optolink's multi-function integrated optical chip MIOC [2] is a solid state waveguide device on X-cut LiNbO_3 substrate fabricated by High-Temperature Proton Exchange method (HTPE). A very important advantage of proton exchange (PE) waveguides is the following one. In such waveguides the extraordinary refraction index is increasing, while refraction index of ordinary rays is decreasing. As a result, proton exchanged waveguides support propagation only extraordinary polarization modes (TE in case of X-cut LiNbO_3). Therefore, it is no necessary to use a polarizer in the fiber optical gyroscope, which brings additional loss.

Frequency modulate is realized by the phase modulator. A saw tooth voltage, Fig.12, is applied to phase modulator electrodes to realize that.

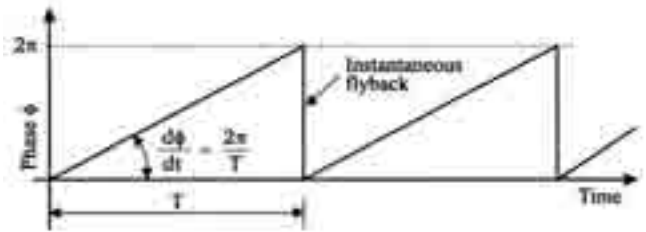


Figure12. A phase modulator voltage

To make a frequency shifter with no sidebands, the phase is varied exactly by 2π , i.e. at 2π phase is reset to 0. The frequency generated depends on the rise time to phase shift of 2π . The instantaneous amplitude of a light wave passing through the modulator is:

$$a = a_0 \sin(2\pi f t + \Phi)$$

where:

a_0 – wave amplitude

f – optical frequency

Φ – phase difference

The slope of the phase ramp is $2\pi/T$. The phase at any instant t is $2\pi t/T$, therefore:

$$a = a_0 \sin\left[2\pi\left(f + \frac{1}{T}\right)t\right]$$

which represents a wave with its frequency shifted by $1/T$. instantaneously subtracting 2π doesn't affect the frequency shift. The generated phase shift is proportional to the measured angular rate:

$$\Delta f = K \Omega$$

so:

$$\Omega = \frac{1}{KT} = \frac{n\lambda}{DT} \quad (32)$$

This method of phase shifting must satisfy the requirements:

- The voltage ramp must vary in slope over the dynamic range of the gyro, always resetting at 2π phase difference
- Any ripple in the rising voltage will generate frequency noise, which can end up at the detector and rise the gyro threshold

- The flyback must be instantaneous to avoid gyro noise. Also if the flyback is no instantaneous that will affect scale factor linearity.

Fig.13 illustrates the digital phase ramp approach.

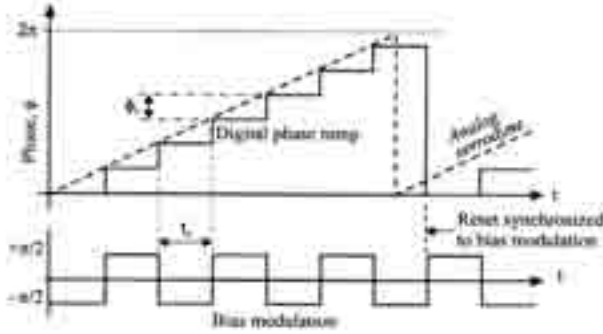


Figure 13. The digital phase ramp

The digital phase ramp is used to improve the scale factor linearity. Instead of ramp generated shift 2π , the modulator provides a step of phase with duration t_d , the transit time in the coil length L :

$$t_d = \frac{L}{c/n} = \frac{nL}{c} \quad (33)$$

Light divides in two beams in the light splitter so that they propagate through coil in opposite ways. One beam enters immediately to the modulator where phase is shifted. To provide maximum sensitivity of modulator (Fig.2) an additional $\pm \frac{\pi}{2}$ bias modulation is introduced.

There is an integrated optical chip (IOC) commercially available as a component or a transceiver which integrates light source, detector and IOC.

Some of producers [2] suggest a fixed frequency of saw tooth voltage, where the amplitude of end of cycle is proportional to angular rate, Fig.14.

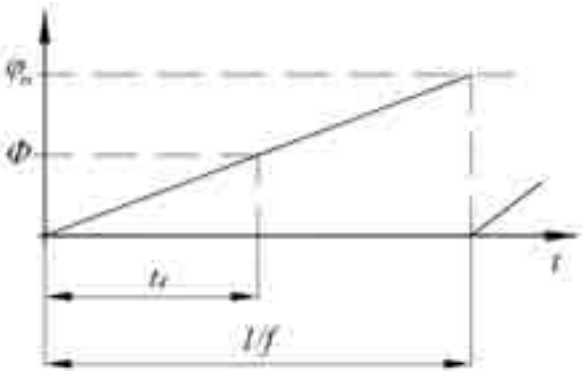


Figure 14. Fixed saw tooth voltage frequency

$$U = \frac{2DV_\pi}{n\lambda f} \Omega \quad (34)$$

The gyro measured angular rate is defined by equation (34). Because V_π is a function of λ , then U is not a function of λ , which improves the gyro temperature stability.

Based on the previous consideration, we can suggest the minimum IFOG configuration realized with 2π phase ramp. The block diagram of the proposed configuration is shown in Fig.15.

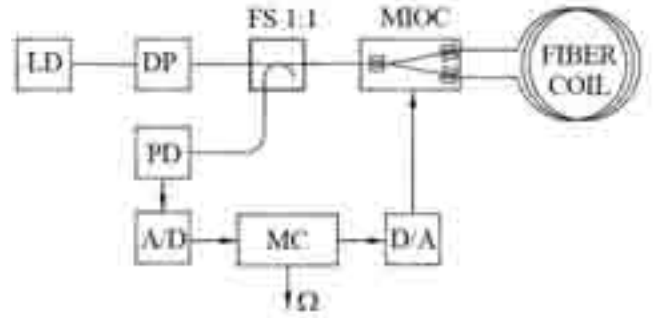


Figure15. A minimum IFOG configuration

The components included in the minimum configuration are:

LD – Laser diode 1550 nm

DP – Depolarizer

FS – Fiber splitter

PD – Photo Detector

A/D – Analog to digital converter

MC – Microcontroller

D/A – Digital to analog converter

Ω – Measured angular rate obtained from IFOG

MIOC – Multifunctional Integrated Optical Chip produced by HTPE technology. The MIOC providing three functions. Firstly, it polarizes the propagating light to reduce bias instability due to polarization non-reciprocity. Secondly, it splits the light into clockwise and counterclockwise waves, each with equal optical power and recombines them with a Y-junction waveguide. Thirdly, with electro-optical phase modulator, it applies a phase ramp and a biasing phase shift between the counter-propagating beams.

FIBER COIL – Polarization Maintaining fiber is used in order to reduce both the drift caused by the polarization cross coupling and the drift caused by earth's and outside magnetic field via the Faraday effect.

Conclusion

As for the angular rate sensors, fiber optical gyroscopes are used as open and closed loop sensors. Open loop gyroscope are less complex and less precise than the closed loop gyroscope, they also have a limited measuring range. Relation between theoretical equations and expected gyro parameters are illustrated based on teal values of gyro components; optical fiber length (L), number of turns (N), wavelength (λ), power at detector P_d , responsivity (R), sampling rate (t_s) and h-parameter.

A procedure of IFOG parameters predetermination is systematized. The results from study [6] are used for the analysis. Some numerical examples are used to illustrate compliance of parameters predetermination with theory and practical results. The obtained results are completely real and correspond to the parameters of IFOGs existing on the market. As an example (Tables 1 and 2), these results should be compared with gyro characteristics declared in [2].

Table 1. IFOG characteristics calculation

Range [°/s]		212 (open loop)
Bias drift [°/h]	Photon Shoot Noise	0.086
	RIN+Photon Shoot Noise	0.318
	From eq. (28)	0.58
Length of fiber		314
Diameter		100

Table 2. IFOG characteristics declared by manufacturer [2]

Parameter	Single axis RRS-2000	Single axis RRS-1000	Single axis RRS-500	Three axes TRS-500	Single axis RRS-200
Range of measured rotation rate, °/sec	±10	from ±5 to ±20 (according to request)	±100	From ±100 to ±500 (according to request)	±200
Bias drift at fixed temperature, °/h	<0.005	from 0.01 to 0.1 (according to request)	<1.0	<1.0	<10.0
Scale factor repeatability, %	≤ 0.02	≤ 0.02	≤ 0.02	≤ 0.02	≤ 0.05
Bandwidth, Hz	10	10-30	100	From 100 to 500	100
Random walk, °/√h	≤0,001	≤0,003	≤0,005	≤0,005	≤0,01
Length of fiber coil, m	2000	1000	500	500	200
Weight (net), kg	1.5	0.8	0.8	1.1	0.8
Dimensions, mm	Ø150x80	Ø150x80	Ø150x80	110x110x90	Ø150x80
Output	Digital	Digital	Analog	Analog or digital	Analog

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Received: 01.12.2008.

Teorijski principi interferometarskog fiberoptičkog žiroskopa i metoda izbora parametara

Prikazana metoda omogućava da se na osnovu teorijskih principa i jednačina koje opisuju rad interferometarskog fiberoptičkog žiroskopa (IFOG) izaberu odgovarajući parametri i komponente koje zadovoljavaju željene zahteve u pogledu opsega, praga osetljivosti, šuma i sl. Na osnovu toga može da se realizuje softver i hardver odgovarajućeg IFOG.

Кljučne reči: žiroskop, žiroskop sa optičkim vlaknom, otvorena petlja, zatvorena petlja, fazna modulacija.

Интерферометрические оптоволоконные гироскопы - принцип работы и выбор главных параметров

Показанный метод обеспечивает на основе теоретических принципов и уравнений, описывающих работу интерферометрического оптоволоконного гироскопа (ИФОГ), выбрать соответствующие параметры и комплектующие части, которые удовлетворяют желанным требованиям мерного предела, порога чувствительности, шума и т.д. На основании всего этого возможно осуществить программное обеспечение и элементы электронных устройств соответствующего ИФОГ.

Ключевые слова: гироскоп, гироскоп с оптическим волокном, открытая петля, закрытая петля, фазная модуляция.

Les gyroscopes interférométriques en fibres optiques. Principe de leur fonctionnement et choix des paramètres de base

La présente méthode, basée sur les principes théoriques et les équations qui décrivent le fonctionnement du gyroscope interférométrique en fibres optiques (IFOG) permet de choisir les paramètres et composants correspondants qui peuvent satisfaire les exigences voulues dans le domaine de la portée, du seuil de sensibilité, bruit, etc. A partir de cela il est possible de réaliser le logiciel et le matériel du IFOG correspondant.

Mots clés: gyroscope, gyroscope à fibre optique, boucle ouverte, boucle fermée, modulation de phase.

