# Fiber Optic Gyros for Robotics

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## Abstract

Measurement of rotational movement is one element in the control of robotic devices. Fiber optic gyroscopes are beginning to replace conventional momentum based techniques. Important attributes of this new technology are no moving parts, high reliability, stable performance and low cost. Many of its components are derived from the fiber optic telecommunications industry. Describes the gyro concept and a specific product, now in production, along with performance data.

## Introduction

Angular rotation is one of the parameters that needs to be accurately measured in order to describe the position of an object moving in space. This is particularly true with robotic applications that depend on dead reckoning navigation, or precise angular orientation. Traditionally, the angular momentum of a spinning rotor was used to determine the angular rate or displacement. These devices are susceptible to damage from shock and vibration, exhibit cross-axis acceleration sensitivity and, for the lower cost versions, have reliability problems. Several alternative technologies are being developed including Coriolis effect rate sensors (also called vibrating beam or tuning fork gyros), however a gyro based on the Sagnac-effect interferometer can be built with no moving parts.

Discovered in 1913, the Sagnac effect [1] found its first practical application several decades ago in the ring laser gyroscope (RLG), now used extensively in commercial inertial navigation systems for aircraft. But, since this implementation requires high vacuum and precision mirror technology, cost has been a factor limiting its application to more mundane tasks.

The physical principal of RLG operation is analogous to the Doppler effect, but in this instance it involves determination of the phase shift between two counterpropagating light beams. For an RLG this occurs in an evacuated mirrored cavity, but in the interferometric fiber optic gyro (IFOG) the same effect can be obtained in a fiber coil [2], eliminating the high voltage and high vacuum, making low-cost inertial rotation sensors practical.

The performance of a fiber optic gyro is mainly characterized by bias stability, scale factor linearity and stability, and a random noise component termed angle random walk (ARW)[3]. Within the scope of IFOG technology are bias stabilities ranging from 1 degree/sec to .001 degrees/hr; scale factor linearities of 10,000 parts per million (ppm) to 1 ppm: and ARW from 200 (deg/hr)/root-Hz to .001 (deg/hr)/root-Hz. The costs, as one might imagine also vary accordingly. For the performance range likely to useful for robotics, however, suitable IFOGs are being built and sold for less than US$1,000.

## Fiber Optic Gyro Concept

Interferometric fiber optic gyros can be configured as either "closed-loop" or open-loop", but the complexity of the former presently restricts it to avionics and inertial navigation grade applications. Figure 1 illustrates the open-loop configuration, which consists of a fiber coil, two directional couplers, a polarizer, optical source and detector. A piezoelectric (PZT) device wound with a small length of one end of the fiber coil applies a non-reciprocal phase modulation.

Light from the laser traverses the first directional coupler, polarizer and second directional coupler where it is split into two signals of equal intensity that travel around the coil in opposite directions. The light recombines at the coupler, returning though the polarizer, and half of the light is directed by the first coupler into a photodetector. Remarkably this configuration permits measuring the difference in phase between the two signals to one part in $10^{16}$. This is possible due to the principal of reciprocity [4]. Light passing from the laser through the polarizer is restricted to a single state of polarization, and the directional couplers and coil are made of special polarization-maintaining fiber to ensure a single mode path. Both directions of light travel are through the same path, and almost all environmental effects except rotation have the same effect on each beam and are canceled.

The laser must exhibit low optical coherence, and often a superluminescent diode or doped fiber operated in the amplified stimulated emission regime is used in higher performance IFOGs, but for rate gyros, a compact disk-type laser operated below threshold has proven to be satisfactory.

At the directional coupler attached to the coil, the two waves merge in an optical interferometer. The light intensity returning from the coil to the polarizer is a raised cosine function (Figure 2), having a maximum value when there is no rotation and a minimum when the optical phase difference is ±π (half an optical wavelength). This effect can be shown to be independent of the shape of the optical path, and of the propagation medium [5]. The and the gyro is sensitive only to rotation about the axis perpendicular to the plane of the coil. Due to the cosine shape, the change in interferometer output is small for small input rotation rates, and it would not be possible to determine the sense of rotation as the decrement in amplitude is equal for both directions of rotation, making it necessary to apply a dynamic phase bias to the light path. Not only does this overcome these problems, but it also moves the demodulation to a frequency well removed from DC, eliminating bias drifts associated with offsets in the low level amplifiers.

**Figure 1** Block diagram of the optical and electronic circuits of an open loop fibre-optic gyroscope

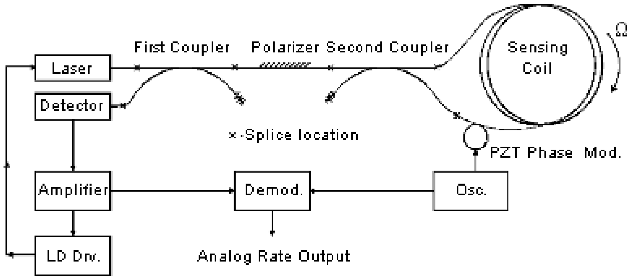
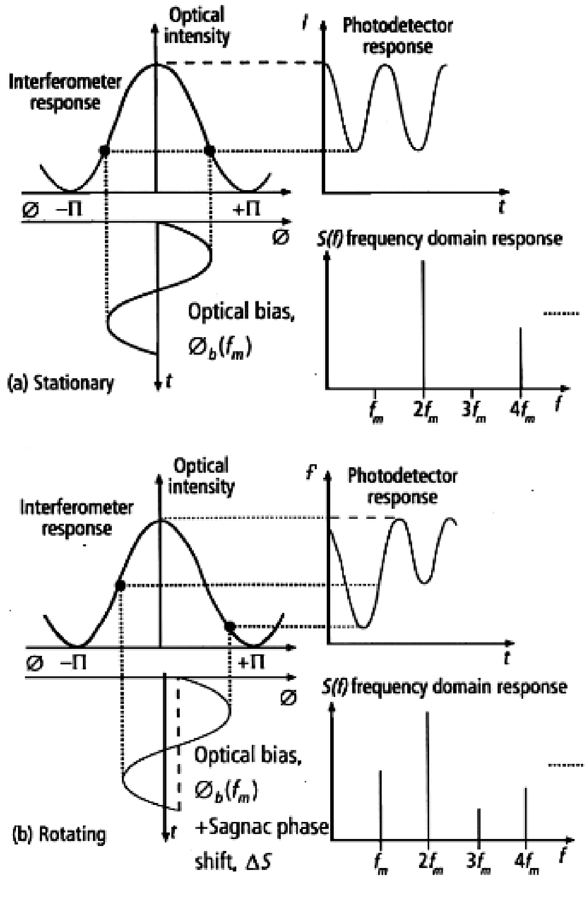


**Figure 2** Sagnac interferometer response for open loop configuration



Modulating the PZT with a sinusoidal voltage impresses a differential optical phase shift between the two light beams at the modulating frequency. The interferometer output for no coil rotation exhibits the periodic behavior of Figure 2a, whose frequency spectrum comprises Bessel harmonics of the modulation frequency. Since the phase modulation is symmetrical, only even harmonics are present; the ratio of the harmonic amplitudes depends on the phase modulation amplitude. When the coil is rotated, the modulation occurs about the shifted position of the interferometer response. The modulation is unbalanced, and the fundamental and odd harmonics will also be present (Figure 2b). The amplitudes of the fundamental and odd harmonics are proportional to the sine of the angular rotation rate, while the even harmonics have a cosine relationship. The simplest demodulation scheme synchronously detects the signal at the fundamental frequency.

The open-loop IFOG is sometimes criticized for the sinusoidal relationship between the input and output characteristics. However since this is a well known analytic function, it can be dealt with by subsequent signal processing. There are also demodulation schemes which take advantage of information in the higher order harmonics to accomplish the same end.

### Performance of a Fiber Optic Rate Gyro

KVH Industries is now producing a IFOG based on these techniques, which is suitable for robotics, stabilization of platforms such as antenna pedestals and optical mounts and dead reckoning land navigation systems. The gyro (Plate 1) operates at an optical wavelength of 820 nanometers, with a 75 meter coil of elliptical-core polarization maintaining fiber. A laser of the compact disc type is used, operating below lasing threshold, and the low coherence reduces unwanted interference between waves reflected from the fusion splices used to join the components. A short coil length results in operation in the linear portion of the sine response curve, without the need for further linearization. The salient specifications of this gyro are:

- maximum input rotation rate (±100 deg/sec);
- scale factor (± 1 percent of full scale, full temperature range);
- bias repeatability (0.02 deg/sec, constant temperature);
- bias offset (0.2 deg/sec (peak-to peak), full temperature);
- angle random walk (20 (deg/hr)/root-Hz (equivalent rotation rate in a 1 Hz bandwidth));
- operating temperature (-40 °C to + 75 °C).

**Plate 1** AUTOGYRO fibre-optic gyro

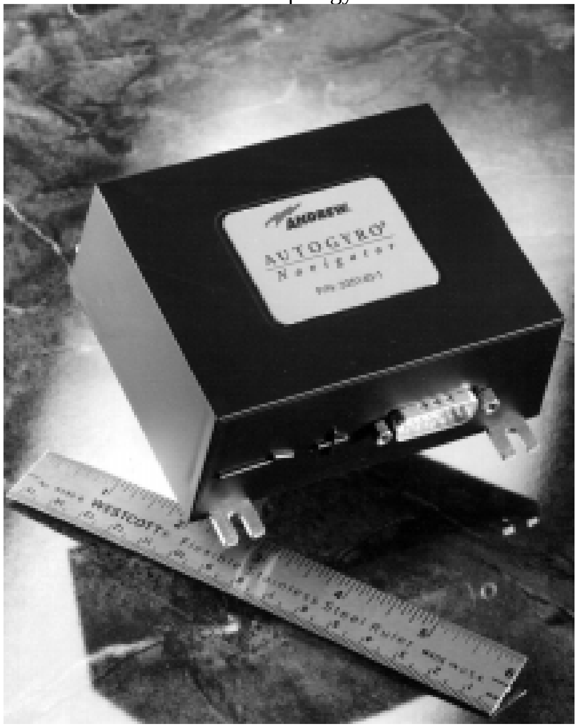
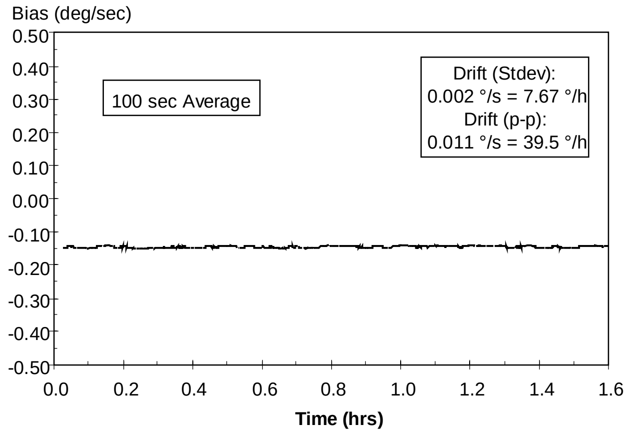


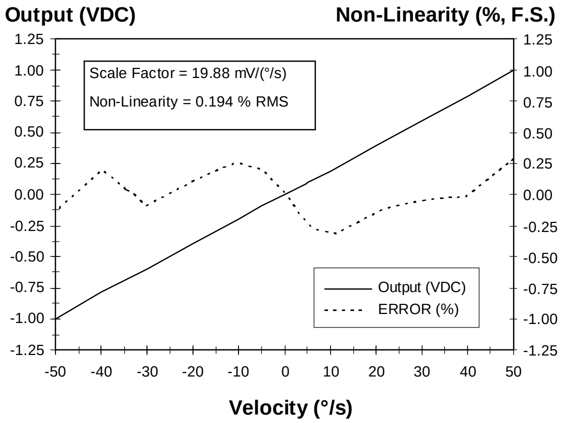
Figure 3 shows the gyro bias drift versus time at a constant temperature; it is less than the angle random walk. The bias varies slowly with temperature due to offsets in DC amplifiers following the detector, but the effect is repeatable and can be calibrated with the aid

**Figure 3** Bias drift versus time



of the internal temperature sensor. The input-output rate relationship is shown in Figure 4, illustrating the excellent linearity that can be achieved by a simple demodulation technique. The product is available with either analog or digital output formats.

**Figure 4** Scale factor linearity



## Summary

In the 20 years since the use of the Sagnac effect for a fiber optic gyro was first proposed, the technology has undergone continual development, and now there is a wide range of gyros based on this principle. The lower performance and lower price versions are particularly suitable for commercial applications. Large volume production of these products is expected to further reduce the cost.

## References

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