United States Patent	12392612
Kind Code	B2
Date of Patent	August 19, 2025
Inventor(s)	Qiu; Tiequn et al.

Systems and methods for effective relative intensity noise subtraction for a broadband resonator optical gyroscope

Abstract

A method of operating a resonator optical gyroscope includes generating optical signals having broadband frequency range; coupling optical signals into optical resonator (OR) to propagate in first direction and out of OR after optical signals pass through OR in first direction; applying phase modulation to optical signals coupled out of OR to generate phase-modulated optical signals; filtering first portion of phase-modulated optical signals to generate filtered, phase-modulated optical signals; generating first electrical signals indicative of power level of the filtered, phase-modulated optical signals and RIN; coupling second portion of phase-modulated optical signals into OR to propagate in second direction and out of OR after phase-modulated optical signals pass through the OR in second direction; generating second electrical signals indicative of power level of phase-modulated optical signals after passing through OR in second direction; and determining a rotation rate based on the first electrical signals and the second electrical signals.

Inventors: **Qiu; Tiequn (Glendale, AZ), Wu; Jianfeng (Tucson, AZ), Sanders; Glen A. (Scottsdale, AZ), Puckett; Matthew Wade (Phoenix, AZ), Tin; Steven (Edina, MN)**

Applicant: **Honeywell International Inc.** (Charlotte, NC)

Family ID: **1000008766625**

Assignee: **Honeywell International Inc. (Charlotte, NC)**

Appl. No.: **18/479505**

Filed: **October 02, 2023**

Prior Publication Data

Document Identifier	Publication Date
US 20250109941 A1	Apr. 03, 2025

Publication Classification

Int. Cl.: **G01C19/72** (20060101); **G02B6/293** (20060101); **H01S3/067** (20060101)

U.S. Cl.:

CPC **G01C19/727** (20130101); **G01C19/721** (20130101); **H01S3/06791** (20130101); **H01S3/06795** (20130101); G02B6/2934 (20130101); G02B6/29347 (20130101); H01S2301/02 (20130101)

Field of Classification Search

CPC: G01C (19/727); G01C (19/721); H01S (3/06791); H01S (3/06795); H01S (2301/02); G02B (6/2934); G02B (6/29347)

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
6204921	12/2000	Strandjord et al.	N/A	N/A
8009296	12/2010	Sanders et al.	N/A	N/A
8068233	12/2010	Qiu et al.	N/A	N/A
8446590	12/2012	Sanders et al.	N/A	N/A
8873063	12/2013	Sanders et al.	N/A	N/A
9207082	12/2014	Qiu et al.	N/A	N/A
9252559	12/2015	Narayanan et al.	N/A	N/A
9568317	12/2016	Croker et al.	N/A	N/A
11131547	12/2020	Digonnet et al.	N/A	N/A
2015/0345949	12/2014	Honthaas et al.	N/A	N/A
2018/0328732	12/2017	Sanders	N/A	H01S 5/1071

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
109282805	12/2018	CN	N/A
115112111	12/2021	CN	N/A
115112113	12/2021	CN	N/A
2333483	12/2018	EP	N/A

OTHER PUBLICATIONS

European Patent Office, “Extended European Search Report”, dated Mar. 18, 2025, from EP Application No. 24199190.0, from Foreign Counterpart to U.S. Appl. No. 18/479,505, pp. 1 through 8, Published: EP. cited by applicant

Liu et al. “Performance of a resonant fiber-optic gyroscope based on a broadband source”, Applied Optics, vol. 61, No. 16, Jun. 1, 2022, pp. 4971 through 4979. cited by applicant

Zhang et al., “Angular Random Walk Improvement of Fiber-Optic Gyroscope Using Active Fiber Ring Resonator”, Optics Letters, 44(7): 1793-1796, Apr. 2019, pp. 1 through 5. cited by applicant

Zhang et al., “Fiber optic gyroscope noise reduction with fiber ring resonator”, Applied Optics, Sep. 2018, vol. 57, No. 25, published Aug. 31, 2018, pp. 7391 through 7397. cited by applicant

Zhao et al., “Navigation-grade resonant fiber-optic gyroscope using ultra-simple white-light multi-

beam interferometry", Photonics Research, Feb. 2022, vol. 10, No. 2, posted Dec. 21, 2021, pp. 542 through 549. cited by applicant
Liu et al., "Reduction of relative intensity noise in a broadband source-driven RFOG using a high-frequency modulation technique", Optics Letters, Oct. 2022, vol. 47, No. 19, published Sep. 27, 2022, pp. 5100 through 5103. cited by applicant

---

Primary Examiner: Luu; Thanh

Assistant Examiner: Tran; Mai Thi Ngoc

Attorney, Agent or Firm: Fogg & Powers LLC

Background/Summary

BACKGROUND
(1) Resonator fiber optic gyroscopes (RFOGs) typically utilize narrow linewidth laser sources to generate the optical signals necessary for rotation rate measurements. An RFOG generally operates by propagating the optical signals generated by the laser through an optical resonator in counter-propagating directions. The resonance frequencies of the optical resonator are frequency-shifted due to the Sagnac effect when the RFOG experiences a rotation about its sense axis. The frequency shift of the resonance frequencies can then be used to determine the extent of rotation experienced by the RFOG.
SUMMARY
(2) In some aspects, a resonator optical gyroscope includes a broadband light source configured to generate optical signals having a broadband frequency range and an optical resonator. The resonator optical gyroscope further includes a first optical coupler configured to receive the optical signals from the broadband light source and couple the optical signals into the optical resonator such that the optical signals propagate in a first direction through the optical resonator. The resonator optical gyroscope further includes a second optical coupler coupled to the optical resonator, wherein the second optical coupler is configured to couple optical signals out of the optical resonator after the optical signals pass through the optical resonator in the first direction. The resonator optical gyroscope further includes a phase modulator configured to apply a phase modulation to optical signals that have been coupled out of the optical resonator by the second optical coupler to generate phase-modulated optical signals. The resonator optical gyroscope further includes an optical filter configured to filter a first portion of the phase-modulated optical signals to generate filtered, phase-modulated optical signals. The second optical coupler is configured to couple a second portion of the phase-modulated optical signals into the optical resonator such that the phase-modulated optical signals propagate in a second direction through the optical resonator. The first optical coupler is configured to couple the second portion of the phase-modulated optical signals out of the optical resonator after the phase-modulated optical signals pass through the optical resonator in the second direction. The resonator optical gyroscope further includes a relative intensity noise detector configured to convert the filtered, phase-modulated optical signals to first electrical signals indicative of a power level of the filtered, phase-modulated optical signals and relative intensity noise. The resonator optical gyroscope further includes a second photodetector configured to convert the phase-modulated optical signals to second electrical signals indicative of a power level of the phase-modulated optical signals after passing through the optical resonator in the second direction. The resonator optical gyroscope further includes one or more circuits configured to determine a rate of rotation based on the first electrical signals and the

second electrical signals.

(3) In some aspects, a resonator optical gyroscope includes a broadband light source configured to generate optical signals having a broadband frequency range and an optical resonator. The resonator optical gyroscope further includes a first optical coupler configured to receive the optical signals from the broadband light source and couple the optical signals into the optical resonator such that the optical signals propagate in a first direction through the optical resonator. The resonator optical gyroscope further includes a second optical coupler coupled to the optical resonator, wherein the second optical coupler is configured to couple optical signals out of the optical resonator after the optical signals pass through the optical resonator in the first direction. The resonator optical gyroscope further includes a phase modulator configured to apply a phase modulation to optical signals that have been coupled out of the optical resonator by the second optical coupler to generate phase-modulated optical signals. The resonator optical gyroscope further includes an optical resonator filter configured to filter a first portion of the phase-modulated optical signals to generate filtered, phase-modulated optical signals. The second optical coupler is configured to couple a second portion of the phase-modulated optical signals into the optical resonator such that the phase-modulated optical signals propagate in a second direction through the optical resonator. The first optical coupler is configured to couple the phase-modulated optical signals out of the optical resonator after the phase-modulated optical signals pass through the optical resonator in the second direction. The resonator optical gyroscope further includes a relative intensity noise detector configured to convert the filtered, phase-modulated optical signals to first electrical signals indicative of a power level of the filtered, phase-modulated optical signals and relative intensity noise. The resonator optical gyroscope further includes a second photodetector configured to convert the phase-modulated optical signals after passing through the optical resonator in the second direction to second electrical signals indicative of a power level of the phase-modulated optical signals. The resonator optical gyroscope further includes one or more circuits configured to determine a rate of rotation based on the first electrical signals and the second electrical signals.

(4) In some aspects, a method of operating a resonator optical gyroscope includes generating, with a broadband light source, optical signals having a broadband frequency range. The method further includes coupling, with a first optical coupler, the optical signals into an optical resonator to propagate in a first direction. The method further includes coupling, with a second optical coupler, the optical signals out of the optical resonator after the optical signals pass through the optical resonator in the first direction. The method further includes applying a phase modulation to the optical signals coupled out of the optical resonator by the second optical coupler to generate phase-modulated optical signals. The method further includes filtering, with an optical filter, a first portion of the phase-modulated optical signals to generate filtered, phase-modulated optical signals. The method further includes generating, with a relative intensity noise detector, first electrical signals indicative of a power level of the filtered, phase-modulated optical signals and relative intensity noise. The method further includes coupling, with the second optical coupler, a second portion of the phase-modulated optical signals into the optical resonator to propagate in a second direction. The method further includes coupling, with the first optical coupler, the phase-modulated optical signals out of the optical resonator after the phase-modulated optical signals pass through the optical resonator in the second direction. The method further includes generating, with a second photodetector, second electrical signals indicative of a power level of the phase-modulated optical signals after passing through the optical resonator in the second direction. The method further includes determining a rotation rate based on the first electrical signals and the second electrical signals.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) Understanding that the drawings depict only some embodiments and are not therefore to be considered limiting in scope, the exemplary embodiments will be described with additional specificity and detail using the accompanying drawings, in which:

(2) FIG. **1** is a block diagram of an example system;

(3) FIG. **2** is a diagram of an optical spectrum of optical signals at different stages in an example optical gyroscope;

(4) FIG. **3**A is a diagram of transmission spectrum of a resonator optical gyroscope and an optical filter;

(5) FIG. **3**B is a diagram of transmission spectrum of a resonator optical gyroscope and an optical filter; and

(6) FIG. **4** is a flow diagram of an example method of relative intensity noise subtraction for a resonator optical gyroscope.

(7) In accordance with common practice, the various described features are not drawn to scale but are drawn to emphasize specific features relevant to the example embodiments.

DETAILED DESCRIPTION

(8) In the following detailed description, reference is made to the accompanying drawings that form a part hereof, and in which are shown by way of illustration specific illustrative embodiments. However, it is to be understood that other embodiments may be utilized, and that logical, mechanical, and electrical changes may be made. Furthermore, the method presented in the drawing figures and the specification is not to be construed as limiting the order in which the individual steps may be performed. The following detailed description is, therefore, not to be taken in a limiting sense.

(9) RFOGs using a broadband light source have recently emerged as a potential apparatus for rotation rate sensing with reduced fiber length, simpler configurations, and potential competitive performance. However, RFOGs using a broadband light source have an issue related to the broadband light source spectrum being significantly filtered by the resonator such that the relative intensity noise at the rate detector is much higher than would be experienced with an interferometer fiber optical gyroscope (IFOG).

(10) One potential option to reduce the relative intensity noise is to measure the relative intensity noise of the optical signals at some point in the optical path after the optical signals pass through the optical resonator and phase modulation is applied. The measured relative intensity noise is then subtracted from the electrical signal generated from the rate photodetector for the rate output of the optical resonator gyroscope. However, a problem with this approach is that the optical spectrum at the rate detector is substantially different from the optical spectrum at other points in the optical path of the optical resonator gyroscope due to the filtering of optical signals by the optical resonator. The light that reaches the rate detector passes through the optical resonator twice while the light that reaches the RIN subtraction detector only passes through the optical resonator once. The mismatch of optical spectrum renders simple relative noise intensity subtraction techniques ineffective.

(11) The techniques described herein address the issue of relative intensity noise by utilizing an optical filter at a particular position in the optical path, which modifies the spectrum of the optical signals sampled to generate electrical signals for relative intensity noise subtraction to have an optical spectrum that more closely aligns to the optical spectrum of the phase-modulated optical signals sampled for rate detection. In some examples, the optical filter is adjusted or tuned using a servo in order to better match the optical spectrums over time. The techniques described herein improve the relative intensity noise subtraction and lead to more accurate rate detection performance for the resonator optical gyroscope utilizing a broadband light source.

(12) FIG. **1** illustrates a block diagram of an example resonator optical gyroscope **100** in which the

techniques for effective relative intensity noise subtraction can be implemented. In the example shown in FIG. **1**, the resonator optical gyroscope **100** includes various components, including a broadband light source **102**, first circulator **104**, first optical coupler **106**, optical resonator **108**, second optical coupler **110**, second circulator **112**, phase modulator **114**, optical filter **116**, relative intensity noise (RIN) detector **118**, rate photodetector **120**, and a RIN subtraction and rate detection circuit **122**. Although not specifically labelled in FIG. **1**, the components of the resonator optical gyroscope **100** are coupled via suitable guided optics. For example, the components of the resonator optical gyroscope **100** can be coupled via optical waveguides and/or free space optics such as lenses, mirrors, and beam splitters. In some examples, the resonator optical gyroscope **100** is implemented on an integrated photonics substrate, such as a photonics chip.

(13) The resonator optical gyroscope **100** generally operates by propagating optical signals through different optical pathways, where they are ultimately processed to determine a rotation rate experienced by the RIN subtraction and rate detection circuit **122** of the resonator optical gyroscope **100**.

(14) The broadband light source **102** is configured to generate the optical signals with a broadband frequency range. In some examples, the broadband light source **102** is configured to generate optical signals via amplified spontaneous emission (ASE). In some examples, the broadband light source **102** is a rare-earth doped fiber or other waveguide light source. For example, the broadband light source **102** can be a fiber doped with rare-earth ions such as erbium, ytterbium, or the like. In such examples, the broadband light source **102** is optically pumped (for example, using a 980 nm or 1480 nm pump lasers), absorbs the pump light, and emits the optical signals. In some examples, the broadband light source **102** can be a superluminescent laser diode, light emitting diode (LED), or the like. In any case, the optical signals generated by broadband light source **102** have a continuous broadband optical spectrum and low coherence that reduces the effects from the optical Kerr effect or renders such effects negligible.

(15) In the example shown in FIG. **1**, the optical signals generated by the broadband light source **102** are provided to a first circulator **104**. In the example shown in FIG. **1**, the first circulator **104** is a three-port device configured to output signals received at one port to another particular port. In the example shown in FIG. **1**, optical signals received from the broadband light source **102** at a first port (shown as port **1** of the first circulator **104**) are output to a second port (shown as port **2** of the first circulator **104**) coupled to the first optical coupler **106**. In the example shown in FIG. **1**, optical signals received from the first optical coupler **106** at the second port are output to a third port (shown as port **3** of the first circulator **104**) and then to the rate photodetector **120**.

(16) The first circulator **104** is configured to provide the optical signals received from the broadband light source **102** to the first optical coupler **106**, and the first optical coupler **106** is configured to couple at least a portion of the optical signals into the optical resonator **108**. In some examples, the fiber extending past the first optical coupler **106** is angle cleaved in order to prevent back reflection of the portion of the optical signals that are not transmitted into the optical resonator **108**. In other examples, an optical isolator or a similar device could also be used to prevent back reflection. In any case, the prevention of back reflection ensures that these signals do not interfere with the other signals that are received by the rate photodetector **120** (including the optical signals generated by broadband light source **102** and the phase-modulated optical signals, as further described herein).

(17) The optical resonator **108** is configured to pass a portion of the coupled optical signals at one or more resonance frequencies of the optical resonator **108**. When the first optical coupler **106** receives the optical signals from the first circulator **104**, it directs the optical signals to propagate in a first direction in the optical resonator **108**. In the example shown in FIG. **1**, the optical signals coupled into the optical resonator **108** by the first optical coupler **106** propagate in the counterclockwise (CCW) direction; however, in other examples the resonator optical gyroscope **100** can be designed such that the optical signals propagate initially in the clockwise (CW)

direction. As the optical signals propagate in the optical resonator **108**, some frequency components of the optical signals (particularly frequency components that are not near the resonance frequency of the optical resonator **108**) will interfere destructively and not resonate. Thus, the frequency components of the optical signals that correspond to the resonance frequencies of the optical resonator **108** will get transmitted to the output port (second optical coupler **110**), while other frequency components will not.

(18) After propagating through the optical resonator **108**, a portion of the optical signals are coupled out of the optical resonator **108** via a second optical coupler **110**. The optical filtering of the optical signals in the first passage through the optical resonator **108** reshapes the broadband optical spectrum to match the optical resonator transmission lines. As shown in FIG. **1**, the optical signals coupled out of the optical resonator **108** have a significantly reduced power level and are channelized by the multiple resonances in the CCW direction.

(19) The optical signals coupled out of the optical resonator **108** via the second optical coupler **110** are then sent to a second circulator **112**. In the example shown in FIG. **1**, the second circulator **112** is a three-port device configured to output signals received at one port to another particular port. In the example shown in FIG. **1**, optical signals received from the second optical coupler **110** at a first port (shown as port **1** of the second circulator **112**) are output to a second port (shown as port **2** of second circulator **112**) coupled to the phase modulator **114**. In the example shown in FIG. **1**, optical signals received from the phase modulator **114** at a third port (shown as port **3** of the second circulator **112**) are output to the first port and then to the second optical coupler **110**.

(20) In the example shown in FIG. **1**, the optical signals output from port **2** of the second circulator **112** are provided to a phase modulator **114**. The phase modulator **114** is configured to modulate the phase of the optical signals based on a phase modulation signal that is sent to the phase modulator **114** from the RIN subtraction and rate detection circuit **122**. In some examples, the phase modulator **114** is configured to generate phase-modulated optical signals using a sawtooth waveform. In some examples, the phase modulator **114** is an electro-optic phase modulator.

(21) Once modulated by phase modulator **114**, the modulated optical signals (referred to as "phase-modulated optical signals") are sent back to the optical resonator **108** in the reverse direction through the second circulator **112** and the second optical coupler **110**. After modulation, the phase-modulated optical signals are provided to the third port of the second circulator **112**. The phase-modulated optical signals received at the third port of the second circulator **112** are output to the first port of the second circulator **112**, which then passes the phase-modulated optical signals back to the second optical coupler **110**. The second optical coupler **110** is configured to couple at least a portion of the phase-modulated optical signals into the optical resonator **108**.

(22) While some of the signal intensity is coupled into the optical resonator **108**, a residual amount of signal propagates toward the fiber extending past the second optical coupler **110**. In some examples, the fiber extending past the second optical coupler **110** is angle cleaved in order to prevent back reflection of the portion of the phase-modulated optical signals that are not transmitted into the optical resonator **108**. In other examples, an optical isolator or a similar device could also be used to prevent back reflection. In any case, the prevention of back reflection ensures that these signals do not interfere with the other signals that are received by the second optical coupler **110**.

(23) The second optical coupler **110** couples the phase-modulated optical signals in a second direction through the optical resonator **108**. In the example shown in FIG. **1**, the phase-modulated optical signals propagate in the CW direction. The phase-modulated optical signals with frequency components corresponding to a resonance peak of the optical resonator **108** propagate through the optical resonator **108**, while non-resonance frequency components are rejected.

(24) After the phase-modulated optical signals propagate through the optical resonator **108**, the first optical coupler **106** is configured to couple a portion of the phase-modulated optical signals out of the optical resonator **108**, and the phase-modulated optical signals are directed to the first circulator

104. Since the phase-modulated optical signals are propagating in a direction towards the broadband light source **102** and received at the second port of the first circulator **104**, the first circulator **104** acts as an isolator to direct the phase-modulated optical signals to the rate photodetector **120** and prevent the phase-modulated optical signals from propagating back to the broadband light source **102**.

(25) The phase-modulated optical signals propagate from the first circulator **104** to the rate photodetector **120**. The rate photodetector **120** is configured to convert the phase-modulated optical signals from an optical signal to a corresponding electrical signal, based on the power of the received phase-modulated optical signals. The electrical signal corresponding to the phase-modulated optical signals is then provided to a RIN subtraction and rate detection circuit **122**.

(26) The optical spectrum of the optical signals generated from the broadband light source **102** vary significantly after the optical signals pass through the optical resonator **108** and have phase modulation applied. FIG. **2** is a diagram **200** of the optical spectrum of the optical signals for a single resonance at various stages of the optical path for the resonator optical gyroscope **100**. In the example shown in FIG. **2**, the line **202** represents the optical spectrum of the optical signals after passing through the optical resonator **108** in the first direction and before phase modulation is applied using the phase modulator **114**. As can be seen in FIG. **2**, the optical spectrum of the optical signals is quite defined after passage through the optical resonator **108**, which is described above as the filtering/channelizing effect of the optical resonator **108**.

(27) In the example shown in FIG. **2**, the line **204** represents the optical spectrum of the phase-modulated optical signals prior to being coupled back into the optical resonator **108** in the second direction by the second optical coupler **110**. In the example shown in FIG. **2**, the peaking shown in the line **204** representing the optical spectrum of the phase-modulated optical signals corresponds to the sidebands of the optical waves after phase modulation is applied using the phase modulator **114**.

(28) In the example shown in FIG. **2**, the line **206** represents the optical spectrum of the phase-modulated optical signals provided to the rate photodetector **120** after passing through the optical resonator **108** in the second direction. As can be seen in FIG. **2**, the power level of the resonance peak for the phase-modulated optical signals provided to the rate photodetector **120** is reduced compared to the power level of the phase-modulated optical signals prior to passage through the optical resonator **108** in the second direction. Further, the power level of the sidebands for the phase-modulated optical signals provided to the rate photodetector **120** is significantly reduced compared to the power level of the sidebands of the phase-modulated optical signals prior to passage through the optical resonator **108** in the second direction.

(29) Due to the mismatch in the optical spectrums represented by lines **204**, **206** in FIG. **2**, current techniques for relative intensity noise subtraction are insufficient to adequately reduce the relative intensity noise.

(30) In the example shown in FIG. **1**, the resonator optical gyroscope **100** further includes an optical filter **116** optically coupled between the phase modulator **114** and the port **3** of the second circulator **112** in order to provide more effective relative intensity noise subtraction. In the example shown in FIG. **1**, a third optical coupler **115** is configured to couple at least a portion of the phase-modulated optical signals into the optical filter **116**. In some examples, the phase-modulated optical signals pass through the optical filter **116** in a direction as that is the same as the first direction of the optical resonator **108**. In the example shown in FIG. **1**, the phase-modulated optical signals pass through the optical filter **116** in the CCW direction. The optical filter **116** transmits the phase-modulated optical signals and generates filtered, phase-modulated optical signals. The optical filtering of the optical signals in the passage through the optical filter **116** reshapes the broadband optical spectrum to match the optical filtering effect of the optical resonator **108** in the second passage through the optical resonator **108**.

(31) The optical filter **116** is configured to filter the phase-modulated optical signals such that the

optical spectrum of the phase-modulated optical signals used for relative intensity noise subtraction approximately matches the optical spectrum of the phase-modulated optical signals provided to the rate photodetector **120**. In the example shown in FIG. **1**, the optical filter **116** is an optical resonator filter and the description below is based on this example. However, it should be understood that other types of optical filters could also be used as long as the optical filter has characteristics similar to those described below.

(32) After propagating through the optical filter **116**, a portion of the filtered, phase-modulated optical signals is coupled out of the optical filter **116** via a fourth optical coupler **117**. The filtered, phase-modulated optical signals coupled out of the optical filter **116** via the fourth optical coupler **117** are provided to the RIN detector **118**. In some examples, RIN detector **118** is configured to measure the intensity fluctuation of the filtered, phase-modulated optical signals at the phase modulation frequency. In some examples, the RIN detector **118** is configured to measure direct current (DC) power and noise for the filtered, phase-modulated optical signals. In some examples, the RIN detector **118** is configured to convert the filtered, phase-modulated optical signals from an optical signal to a corresponding electrical signal, based on the power of the received phase-modulated optical signals and relative intensity noise. In some examples, the RIN detector **118** is configured to output electrical signals indicative of the power level and the relative intensity noise at the modulation frequency of the filtered, phase-modulated optical signals and provide the electrical signals to the RIN subtraction and rate detection circuit **122**.

(33) In some examples, the optical filter **116** is designed to have a cavity that is a similar size to the cavity of the optical resonator **108**. In other examples, the optical filter **116** is designed to have a cavity that is smaller than the cavity of the optical resonator **108** and a higher finesse than the optical resonator **108**. As long as the optical transmission spectrum of the optical filter **116** for the filtered, phase-modulated optical signals approximately matches the optical transmission line shape of the optical resonator **108** for the phase-modulated optical signals, the optical filter **116** can differ from the optical resonator **108** in these or other ways.

(34) In some examples, the optical filter **116** is designed to have a free spectral range (FSR) that is an integer number (n=1, 2, 3, . . .) of the FSR of the optical resonator **108**. FIG. **3**A illustrates an optical transmission spectrum **302** of the optical filter **116** and an optical transmission spectrum **304** of the optical resonator **108** where the integer ratio of the FSR of the optical filter **116** to the FSR of the optical resonator **108** is n=10. It should be understood that this is an example and any integer ratio of the FSR of the optical filter **116** to the FSR of the optical resonator **108** of one or greater could be implemented for the resonator optical gyroscope **100**.

(35) In some examples, the optical filter **116** is designed such that the line shape of the optical filter **116** is approximately equal to the line shape of the optical resonator **108**. FIG. **3**B is a diagram **350** of the optical transmission spectrum **352** of the optical resonator **108** and the optical transmission spectrum **354** of the optical filter **116** for a resonance peak (for example, the central resonance peak shown in FIG. **3**A). In some examples, the line shape of the optical filter **116** is considered to be approximately equal to the line shape of the optical resonator **108** if the line shape of the optical transmission spectrum **354** of the optical filter **116** overlaps ninety-five percent or more with the optical transmission spectrum **352** of the optical resonator **108** within an order of magnitude of the resonance peak. In the example shown in FIG. **3**B, the line shape of the optical transmission spectrum **354** of the optical filter **116** matches the optical transmission spectrum **352** of the optical resonator **108** above −20 dB. The deviations below −20 dB shown in FIGS. **3**A-**3**B do not contribute much to relative intensity noise difference, so it is more important (and efficient) to match the top portion of the resonance peaks.

(36) The RIN subtraction and rate detection circuit **122** is configured to subtract the electrical signals received from the RIN detector **118** from the electrical signals received from the rate photodetector **120** to remove relative intensity noise from the electrical signals received from the rate photodetector **120**.

(37) In some examples, the electrical signals from the RIN detector **118** and/or the electrical signals from the rate photodetector **120** are modified prior to subtraction. In some such examples, the gain of the electrical signals from the RIN detector **118** and/or the gain of the electrical signals from the rate photodetector **120** is modified to equalize the power levels of the electrical signals prior to subtraction. The difference between or a ratio of direct current (DC) power levels between the electrical signals from the RIN detector **118** and the electrical signals from the rate photodetector **120** can be used to determine the gain adjustment to apply to the electrical signals from the RIN detector **118** and/or the electrical signals from the rate photodetector **120**.
(38) In order to determine the rotation rate, the RIN subtraction and rate detection circuit **122** is configured to demodulate the electrical signals from the rate photodetector **120** after subtraction of the relative intensity noise using the electrical signals from the RIN detector **118** and further configured to determine the resonance frequency shift based on the power of the demodulated signal corresponding to the phase-modulated optical signals. For example, the received electrical signals from the rate photodetector **120** can be indicative of a power difference corresponding to a change in rotation rate.
(39) In some examples, in order to better match the optical spectrum of the filtered, phase-modulated optical signals coupled out of the optical filter **116** and the optical spectrum of the phase-modulated optical signals coupled out of the optical resonator **108**, the optical filter **116** is locked to the optical resonator **108** so the optical filter **116** does not drift from the optical resonator **108** over time. In some examples, the RIN subtraction and rate detection circuit **122** or another circuit is configured to adjust at least one characteristic of the optical filter **116** to lock the optical filter **116** to the optical resonator **108**. In some examples, the RIN subtraction and rate detection circuit **122** or another circuit is configured to adjust a temperature of the optical filter **116**. In other examples, the RIN subtraction and rate detection circuit **122** or another circuit is configured to modify a length of the optical filter **116** (for example, using a piezoelectric transducer). In some examples, the RIN subtraction and rate detection circuit **122** is configured to lock the optical filter **116** to the optical resonator **108** by maximizing a direct current power level output by the RIN detector **118**.
(40) In some examples, the power level of the phase-modulated optical signals can also be used to adjust the slope of the triangle phase modulation signal (which shifts the frequency of the optical signals), and the slope difference between two successive periods of the phase modulation signal (which apply a square wave frequency modulation to the optical signals) can be used to determine the frequency shift. The RIN subtraction and rate detection circuit **122** can then determine the rotation rate based on the frequency shift.
(41) In some examples, the resonator optical gyroscope **100** shown in FIG. **1** is configured to operate as a closed-loop optical gyroscope because the output from the rate photodetector **120**, indicative of a rotation rate, is also used as feedback to adjust the operation of the phase modulator **114** (wherein the “closed-loop” comprises the propagation of signals from the phase modulator **114** to, ultimately, the RIN subtraction and rate detection circuit **122**, and the control signals input to the phase modulator **114**). In some examples, the RIN subtraction and rate detection circuit **122** includes control circuitry configured to adjust the operation of phase modulator **114** based on the electrical signal from the rate photodetector **120**. In some examples, the RIN subtraction and rate detection circuit **122** configures at least one parameter of the phase modulator **114**, such as the characteristics of the phase modulation signal used by the phase modulator **114** to modulate the optical signals. For example, as previously described, the RIN subtraction and rate detection circuit **122** is configured to adjust the slope(s) of a sawtooth phase modulation signal based on a rotation induced changes determined from the received electrical signal. The RIN subtraction and rate detection circuit **122** can send control signals that configure the phase modulator **114**.
(42) In response to receiving the control signals to adjust the slope of the phase modulation signal, the phase modulator **114** generates an adjusted phase modulation signal with the slope of the

waveform corresponding to the parameters set by the RIN subtraction and rate detection circuit **122**. For example, the phase-modulated optical signals can have a frequency shift that corresponds to the shifted resonance frequency of the optical resonator **108** due to rotation. In this way, the resonator optical gyroscope **100** (and in particular the RIN subtraction and rate detection circuit **122**) can compensate for power fluctuations in the average power of phase-modulated optical signals that are detected by the RIN subtraction and rate detection circuit **122**.

(43) In some examples, to reduce the rate measurement error, the optical resonator **108** can include polarizers (not shown) configured to filter out portions of the optical signals that correspond to undesirable polarization states. For example, the optical resonator **108** can include a polarizer (not shown) configured to filter out portions of the optical signals that correspond to unwanted polarization modes of the optical resonator **108**. As a result, only the portion of the optical signals that correspond to a selected polarization mode of the optical resonator **108** are allowed to pass through the polarizer, and will get transmitted through each round trip through the optical resonator **108**.

(44) FIG. **4** illustrates a flow diagram of an example method **400** of operation of a resonator optical gyroscope. The common features discussed above with respect to the example system in FIGS. **1**-**3**B can include similar characteristics to those discussed with respect to method **400** and vice versa. In some examples, the blocks of the method **400** are performed by resonator optical gyroscope **100** described above.

(45) The method **400** includes generating optical signals having a broadband frequency range (block **402**). In some examples, the optical signals are generated using a broadband light source, which can be an ASE light source, rare-earth doped fiber light source, superluminescent laser diode, a light emitting diode, or the like.

(46) The method **400** further includes coupling the optical signals into an optical resonator to propagate in a first direction (block **404**), and coupling the optical signals out of the optical resonator after the optical signals have completed pass(es) through the optical resonator in the first direction (block **406**). In some examples, the optical signals are coupled into the optical resonator and out of the optical resonator using a first optical coupler and a second optical coupler, respectively.

(47) The method **400** further includes applying a phase modulation to the optical signals (block **408**). In some examples, applying a phase modulation to the optical signals includes using a sawtooth waveform.

(48) The method **400** further includes filtering a first portion of the phase-modulated optical signals with an optical filter (block **410**). In some examples, the filtering is performed using an optical filter (for example, an optical resonator filter). In some examples, the optical filter is designed to have a free spectral range that is an integer multiple of the free spectral range of the optical resonator, and such that a line shape of resonance peaks of optical signals output from the optical filter match the line shape of resonance peaks of optical signals output from the optical resonator. In some examples, the optical filter is locked to the optical resonator by adjusting one or more characteristics of the optical filter.

(49) The method **400** further includes generating electrical signals corresponding to the filtered, phase-modulated optical signals (block **412**). In some examples, the electrical signals are generated by a relative intensity noise detector and indicative of a power level of the filtered, phase-modulated optical signals and relative intensity noise.

(50) The method **400** further includes coupling a second portion of the phase-modulated optical signals into the optical resonator to propagate in a second direction (block **414**), and coupling the phase-modulated optical signals out of the optical resonator after the optical signals have passed through the optical resonator in the second direction (block **416**). In some examples, the phase-modulated optical signals are coupled into the optical resonator and out of the optical resonator using the second optical coupler and the first optical coupler, respectively.

(51) The method **400** further includes generating second electrical signals corresponding to the phase-modulated optical signals after passing through the resonator in the second direction (block **418**). In some examples, the electrical signals are generated by a photodetector and indicative of a power level of the phase-modulated optical signals.
(52) The method **400** further includes determining a rotation rate based on the first electrical signals and the second electrical signals (block **420**). In some examples, determining the rotation rate based on the first electrical signals and the second electrical signals includes subtracting the first electrical signals from the second electrical signals. In some such examples, determining the rotation rate based on the first electrical signals and the second electrical signals includes adjusting the gain of the first electrical signals and/or the second electrical signals prior to the subtraction. In some examples, determining the rotation rate includes demodulating the electrical signals and determining a resonance frequency shift based on the power of the demodulated electrical signal corresponding to the phase-modulated optical signal.
(53) By using an optical filter to filter a portion of the phase-modulated optical signals as described herein, relative intensity noise subtraction for a broadband RFOG can be performed in an effective and efficient manner. Further, by designing the optical filter and locking it to the optical resonator as described herein, the optical filter can be more compact and effective for relative intensity noise subtraction. Overall, the systems and methods described herein can substantially reduce the relative intensity noise induced rate error for a broadband RFOG such that higher performance can be achieved with low cost.
(54) In various aspects, system elements, method steps, or examples described throughout this disclosure (such as the RIN subtraction and rate detection circuit **122**, or components thereof, for example) may be implemented on one or more computer systems including a central processing unit (CPU), graphics processing unit (GPU), field programmable gate array (FPGA), application specific integrated circuit (ASIC) and/or similar devices comprising hardware executing code to realize those elements, processes, or examples, said code stored on a non-transient data storage device. These devices include or function with software programs, firmware, or other computer readable instructions for carrying out various methods, process tasks, calculations, and control functions.
(55) These instructions are typically stored on any appropriate computer readable medium used for storage of computer readable instructions or data structures. The computer readable medium can be implemented as any available media that can be accessed by a general purpose or special purpose computer or processor, or any programmable logic device. Suitable processor-readable media may include storage or memory media such as magnetic or optical media. For example, storage or memory media may include conventional hard disks, Compact Disk-Read Only Memory (CD-ROM), volatile or non-volatile media such as Random Access Memory (RAM) (including, but not limited to, Synchronous Dynamic Random Access Memory (SDRAM), Double Data Rate (DDR) RAM, RAMBUS Dynamic RAM (RDRAM), Static RAM (SRAM), etc.), Read Only Memory (ROM), Electrically Erasable Programmable ROM (EEPROM), and flash memory, etc. Suitable processor-readable media may also include transmission media such as electrical, electromagnetic, or digital signals, conveyed via a communication medium such as a network and/or a wireless link.
(56) The methods and techniques described here may be implemented, in part, in digital electronic circuitry, or with a programmable processor (for example, a special-purpose processor or a general-purpose processor such as a computer) firmware, software, or in combinations of them. Apparatus embodying these techniques may include appropriate input and output devices, a programmable processor, and a storage medium tangibly embodying program instructions for execution by the programmable processor. A process embodying these techniques may be performed by a programmable processor executing a program of instructions to perform desired functions by operating on input data and generating appropriate output. The techniques may advantageously be implemented in one or more programs that are executable on a programmable system including at

least one programmable processor coupled to receive data and instructions from, and to transmit data and instructions to, a data storage system, at least one input device, and at least one output device. Generally, a processor will receive instructions and data from a read-only memory and/or a random access memory. Storage devices suitable for tangibly embodying computer program instructions and data include all forms of non-volatile memory, including by way of example semiconductor memory devices, such as EPROM, EEPROM, and flash memory devices; magnetic disks such as internal hard disks and removable disks; magneto-optical disks; and DVD disks. Any of the foregoing may be supplemented by, or incorporated in, specially-designed application-specific integrated circuits (ASICs).

EXAMPLE EMBODIMENTS

(57) Example 1 includes a resonator optical gyroscope, comprising: a broadband light source configured to generate optical signals having a broadband frequency range; an optical resonator; a first optical coupler configured to receive the optical signals from the broadband light source and couple the optical signals into the optical resonator such that the optical signals propagate in a first direction through the optical resonator; a second optical coupler coupled to the optical resonator, wherein the second optical coupler is configured to couple optical signals out of the optical resonator after the optical signals pass through the optical resonator in the first direction; a phase modulator configured to apply a phase modulation to optical signals that have been coupled out of the optical resonator by the second optical coupler to generate phase-modulated optical signals; an optical filter configured to filter a first portion of the phase-modulated optical signals to generate filtered, phase-modulated optical signals; wherein the second optical coupler is configured to couple a second portion of the phase-modulated optical signals into the optical resonator such that the phase-modulated optical signals propagate in a second direction through the optical resonator, wherein the first optical coupler is configured to couple the second portion of the phase-modulated optical signals out of the optical resonator after the phase-modulated optical signals pass through the optical resonator in the second direction; a relative intensity noise detector configured to convert the filtered, phase-modulated optical signals to first electrical signals indicative of a power level of the filtered, phase-modulated optical signals and relative intensity noise; a second photodetector configured to convert the phase-modulated optical signals to second electrical signals indicative of a power level of the phase-modulated optical signals after passing through the optical resonator in the second direction; and one or more circuits configured to determine a rate of rotation based on the first electrical signals and the second electrical signals.

(58) Example 2 includes the resonator optical gyroscope of Example 1, wherein the one or more circuits are configured to lock the optical filter to the optical resonator by adjusting at least one characteristic of the optical filter.

(59) Example 3 includes the resonator optical gyroscope of Example 2, wherein the one or more circuits are configured to adjust at temperature of the optical filter and/or modify a length of the optical filter with a piezoelectric transducer.

(60) Example 4 includes the resonator optical gyroscope of any of Examples 1-3, wherein the optical filter is configured such that a line shape of resonance peaks of the filtered, phase-modulated optical signals is approximately equal to a line shape of resonance peaks of the phase-modulated optical signals.

(61) Example 5 includes the resonator optical gyroscope of any of Examples 1-4, wherein the one or more circuits are configured to determine the rate of rotation based on the first electrical signals and the second electrical signals by subtracting the first electrical signals from the second electrical signals.

(62) Example 6 includes the resonator optical gyroscope of Example 5, wherein the one or more circuits are configured to adjust a gain of the first electrical signals and/or the second electrical signals prior to subtracting the first electrical signals from the second electrical signals.

(63) Example 7 includes the resonator optical gyroscope of Example 6, wherein the one or more

circuits are configured to adjust the gain of the first electrical signals and/or the second electrical signals based on a difference between direct current power levels of the first electrical signals and the second electrical signals.
(64) Example 8 includes the resonator optical gyroscope of any of Examples 1-7, wherein the one or more circuits are configured to lock the optical filter to the optical resonator by maximizing a direct current power level output by the relative intensity noise detector.
(65) Example 9 includes a resonator optical gyroscope, comprising: a broadband light source configured to generate optical signals having a broadband frequency range; an optical resonator; a first optical coupler configured to receive the optical signals from the broadband light source and couple the optical signals into the optical resonator such that the optical signals propagate in a first direction through the optical resonator; a second optical coupler coupled to the optical resonator, wherein the second optical coupler is configured to couple optical signals out of the optical resonator after the optical signals pass through the optical resonator in the first direction; a phase modulator configured to apply a phase modulation to optical signals that have been coupled out of the optical resonator by the second optical coupler to generate phase-modulated optical signals; an optical resonator filter configured to filter a first portion of the phase-modulated optical signals to generate filtered, phase-modulated optical signals; wherein the second optical coupler is configured to couple a second portion of the phase-modulated optical signals into the optical resonator such that the phase-modulated optical signals propagate in a second direction through the optical resonator, wherein the first optical coupler is configured to couple the phase-modulated optical signals out of the optical resonator after the phase-modulated optical signals pass through the optical resonator in the second direction; a relative intensity noise detector configured to convert the filtered, phase-modulated optical signals to first electrical signals indicative of a power level of the filtered, phase-modulated optical signals and relative intensity noise; a second photodetector configured to convert the phase-modulated optical signals after passing through the optical resonator in the second direction to second electrical signals indicative of a power level of the phase-modulated optical signals; and one or more circuits configured to determine a rate of rotation based on the first electrical signals and the second electrical signals.
(66) Example 10 includes the resonator optical gyroscope of Example 9, wherein the optical resonator filter has a higher finesse than the optical resonator.
(67) Example 11 includes the resonator optical gyroscope of any of Examples 9-10, wherein the one or more circuits are configured to lock the optical resonator filter to the optical resonator by adjusting at least one characteristic of the optical resonator filter.
(68) Example 12 includes the resonator optical gyroscope of any of Examples 9-11, wherein the optical resonator filter is configured such that a free spectral range of the optical resonator filter is an integer number times a free spectral range of the optical resonator.
(69) Example 13 includes the resonator optical gyroscope of any of Examples 9-12, wherein the one or more circuits are configured to determine the rate of rotation based on the first electrical signals and the second electrical signals by subtracting the first electrical signals from the second electrical signals.
(70) Example 14 includes the resonator optical gyroscope of any of Examples 9-13, wherein the one or more circuits are configured to adjust a gain of the first electrical signals and/or the second electrical signals prior to subtracting the first electrical signals from the second electrical signals.
(71) Example 15 includes the resonator optical gyroscope of Example 14, wherein the one or more circuits are configured to adjust the gain of the first electrical signals and/or the second electrical signals prior to subtracting the first electrical signals from the second electrical signals.
(72) Example 16 includes a method of operating a resonator optical gyroscope, comprising: generating, with a broadband light source, optical signals having a broadband frequency range; coupling, with a first optical coupler, the optical signals into an optical resonator to propagate in a first direction; coupling, with a second optical coupler, the optical signals out of the optical

resonator after the optical signals pass through the optical resonator in the first direction; applying a phase modulation to the optical signals coupled out of the optical resonator by the second optical coupler to generate phase-modulated optical signals; filtering, with an optical filter, a first portion of the phase-modulated optical signals to generate filtered, phase-modulated optical signals; generating, with a relative intensity noise detector, first electrical signals indicative of a power level of the filtered, phase-modulated optical signals and relative intensity noise; coupling, with the second optical coupler, a second portion of the phase-modulated optical signals into the optical resonator to propagate in a second direction; coupling, with the first optical coupler, the phase-modulated optical signals out of the optical resonator after the phase-modulated optical signals pass through the optical resonator in the second direction; generating, with a second photodetector, second electrical signals indicative of a power level of the phase-modulated optical signals after passing through the optical resonator in the second direction; and determining a rotation rate based on the first electrical signals and the second electrical signals.
(73) Example 17 includes the method of Example 16, further comprising locking the optical filter to the optical resonator by adjusting at least one characteristic of the optical filter.
(74) Example 18 includes the method of any of Examples 16-17, wherein determining a rotation rate based on the first electrical signals and the second electrical signals includes subtracting the first electrical signals from the second electrical signals.
(75) Example 19 includes the method of any of Examples 16-18, further comprising adjusting a gain of the first electrical signals and/or the second electrical signals prior to subtracting the first electrical signals from the second electrical signals.
(76) Example 20 includes the method of any of Examples 16-19, further comprising locking the optical filter to the optical resonator such that a line shape of resonance peaks of an optical spectrum of the filtered, phase-modulated optical signals is approximately equal to a line shape of resonance peaks of an optical spectrum of the phase-modulated optical signals.
(77) Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement, which is calculated to achieve the same purpose, may be substituted for the specific embodiments shown. Therefore, it is manifestly intended that this invention be limited only by the claims and the equivalents thereof.

Claims

1. A resonator optical gyroscope, comprising: a broadband light source configured to generate optical signals having a broadband frequency range; an optical resonator; a first optical coupler configured to receive the optical signals from the broadband light source and couple the optical signals into the optical resonator such that the optical signals propagate in a first direction through the optical resonator; a second optical coupler coupled to the optical resonator, wherein the second optical coupler is configured to couple optical signals out of the optical resonator after the optical signals pass through the optical resonator in the first direction; a phase modulator configured to apply a phase modulation to optical signals that have been coupled out of the optical resonator by the second optical coupler to generate phase-modulated optical signals; an optical filter configured to filter a first portion of the phase-modulated optical signals to generate filtered, phase-modulated optical signals; wherein the second optical coupler is configured to couple a second portion of the phase-modulated optical signals into the optical resonator such that the phase-modulated optical signals propagate in a second direction through the optical resonator, wherein the first optical coupler is configured to couple the second portion of the phase-modulated optical signals out of the optical resonator after the phase-modulated optical signals pass through the optical resonator in the second direction; a relative intensity noise detector configured to convert the filtered, phase-modulated optical signals to first electrical signals indicative of a power level of the filtered, phase-modulated optical signals and relative intensity noise; a second photodetector configured to convert

the phase-modulated optical signals to second electrical signals indicative of a power level of the phase-modulated optical signals after passing through the optical resonator in the second direction; and one or more circuits configured to determine a rate of rotation based on the first electrical signals and the second electrical signals.
2. The resonator optical gyroscope of claim 1, wherein the one or more circuits are configured to lock the optical filter to the optical resonator by adjusting at least one characteristic of the optical filter.
3. The resonator optical gyroscope of claim 2, wherein the one or more circuits are configured to adjust at temperature of the optical filter and/or modify a length of the optical filter with a piezoelectric transducer.
4. The resonator optical gyroscope of claim 1, wherein the optical filter is configured such that a line shape of resonance peaks of the filtered, phase-modulated optical signals is approximately equal to a line shape of resonance peaks of the phase-modulated optical signals.
5. The resonator optical gyroscope of claim 1, wherein the one or more circuits are configured to determine the rate of rotation based on the first electrical signals and the second electrical signals by subtracting the first electrical signals from the second electrical signals.
6. The resonator optical gyroscope of claim 5, wherein the one or more circuits are configured to adjust a gain of the first electrical signals and/or the second electrical signals prior to subtracting the first electrical signals from the second electrical signals.
7. The resonator optical gyroscope of claim 6, wherein the one or more circuits are configured to adjust the gain of the first electrical signals and/or the second electrical signals based on a difference between direct current power levels of the first electrical signals and the second electrical signals.
8. The resonator optical gyroscope of claim 1, wherein the one or more circuits are configured to lock the optical filter to the optical resonator by maximizing a direct current power level output by the relative intensity noise detector.
9. A resonator optical gyroscope, comprising: a broadband light source configured to generate optical signals having a broadband frequency range; an optical resonator; a first optical coupler configured to receive the optical signals from the broadband light source and couple the optical signals into the optical resonator such that the optical signals propagate in a first direction through the optical resonator; a second optical coupler coupled to the optical resonator, wherein the second optical coupler is configured to couple optical signals out of the optical resonator after the optical signals pass through the optical resonator in the first direction; a phase modulator configured to apply a phase modulation to optical signals that have been coupled out of the optical resonator by the second optical coupler to generate phase-modulated optical signals; an optical resonator filter configured to filter a first portion of the phase-modulated optical signals to generate filtered, phase-modulated optical signals; wherein the second optical coupler is configured to couple a second portion of the phase-modulated optical signals into the optical resonator such that the phase-modulated optical signals propagate in a second direction through the optical resonator, wherein the first optical coupler is configured to couple the phase-modulated optical signals out of the optical resonator after the phase-modulated optical signals pass through the optical resonator in the second direction; a relative intensity noise detector configured to convert the filtered, phase-modulated optical signals to first electrical signals indicative of a power level of the filtered, phase-modulated optical signals and relative intensity noise; a second photodetector configured to convert the phase-modulated optical signals after passing through the optical resonator in the second direction to second electrical signals indicative of a power level of the phase-modulated optical signals; and one or more circuits configured to determine a rate of rotation based on the first electrical signals and the second electrical signals.
10. The resonator optical gyroscope of claim 9, wherein the optical resonator filter has a higher finesse than the optical resonator.

11. The resonator optical gyroscope of claim 9, wherein the one or more circuits are configured to lock the optical resonator filter to the optical resonator by adjusting at least one characteristic of the optical resonator filter.
12. The resonator optical gyroscope of claim 9, wherein the optical resonator filter is configured such that a free spectral range of the optical resonator filter is an integer number times a free spectral range of the optical resonator.
13. The resonator optical gyroscope of claim 9, wherein the one or more circuits are configured to determine the rate of rotation based on the first electrical signals and the second electrical signals by subtracting the first electrical signals from the second electrical signals.
14. The resonator optical gyroscope of claim 9, wherein the one or more circuits are configured to adjust a gain of the first electrical signals and/or the second electrical signals prior to subtracting the first electrical signals from the second electrical signals.
15. The resonator optical gyroscope of claim 14, wherein the one or more circuits are configured to adjust the gain of the first electrical signals and/or the second electrical signals prior to subtracting the first electrical signals from the second electrical signals.
16. A method of operating a resonator optical gyroscope, comprising: generating, with a broadband light source, optical signals having a broadband frequency range; coupling, with a first optical coupler, the optical signals into an optical resonator to propagate in a first direction; coupling, with a second optical coupler, the optical signals out of the optical resonator after the optical signals pass through the optical resonator in the first direction; applying a phase modulation to the optical signals coupled out of the optical resonator by the second optical coupler to generate phase-modulated optical signals; filtering, with an optical filter, a first portion of the phase-modulated optical signals to generate filtered, phase-modulated optical signals; generating, with a relative intensity noise detector, first electrical signals indicative of a power level of the filtered, phase-modulated optical signals and relative intensity noise; coupling, with the second optical coupler, a second portion of the phase-modulated optical signals into the optical resonator to propagate in a second direction; coupling, with the first optical coupler, the phase-modulated optical signals out of the optical resonator after the phase-modulated optical signals pass through the optical resonator in the second direction; generating, with a second photodetector, second electrical signals indicative of a power level of the phase-modulated optical signals after passing through the optical resonator in the second direction; and determining a rotation rate based on the first electrical signals and the second electrical signals.
17. The method of claim 16, further comprising locking the optical filter to the optical resonator by adjusting at least one characteristic of the optical filter.
18. The method of claim 16, wherein determining a rotation rate based on the first electrical signals and the second electrical signals includes subtracting the first electrical signals from the second electrical signals.
19. The method of claim 16, further comprising adjusting a gain of the first electrical signals and/or the second electrical signals prior to subtracting the first electrical signals from the second electrical signals.
20. The method of claim 16, further comprising locking the optical filter to the optical resonator such that a line shape of resonance peaks of an optical spectrum of the filtered, phase-modulated optical signals is approximately equal to a line shape of resonance peaks of an optical spectrum of the phase-modulated optical signals.