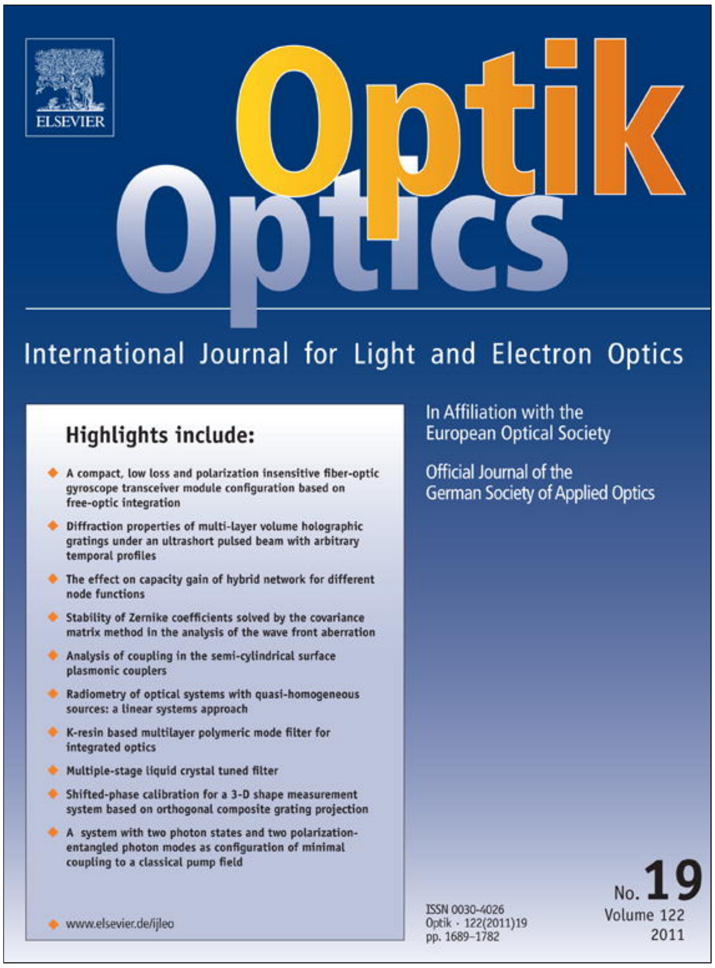
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A compact, low loss and polarization insensitive fiber-optic gyroscope transceiver module configuration based on free-optic integration

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ABSTRACT

A compact, low loss and polarization insensitive transceiver module configuration based on free-space integration which is applicable to a high sensitive and miniature fiber-optic gyroscope is proposed. The basic idea of this module is to construct a double power output configuration so that both of the powers of the two split orthogonal polarized components of the source propagating along different paths can be utilized fully which thus improves the signal-to-noise (SNR). In addition, the signal intensity received by the detector is insensitive to the source polarization and is independent of the power ratio of the two split orthogonal polarized beams, which relaxes the polarization specification of source and simplifies the integration processes of transceiver module.

1. Introduction

A fiber-optic gyroscope is a device that uses the phase difference (Sagnac effect) between two light waves traveling in opposite direction around an optical fiber coil to measure inertial rotation of the fiber coil. The amount of the phase shift of the two light waves can be measured by determining the interference intensity of the combined two light waves which depends on the rotation rate of the fiber coil about its axis. For the traditional transceiver module configuration applicable to the fiber-optic gyroscope, as shown in Fig. 1(a), the key optical components (superluminescent diode (SLD), coupler, detector and so on) are integrated by fiber coupling so that it is bulky and incompact. Moreover, the fiber coupler used in the transceiver module introduces the 6 dB inherent loss. A small, compact and low loss transceiver module in a highly integrated form factor is the trend for the research and development of the high sensitive and miniature fiber-optic gyroscope. Several approaches to form the compact transceiver module have been reported [1–10]. Among these approaches, Free-space coupling is an effective way to integrate the optical components into a compact transceiver module. Kuniyoshi used a cube beam splitter and lens to make the free-space integrated transceiver module of fiber-optic gyroscope smaller [1], as shown in Fig. 1(b), but the cube-beam-splitter employed as the coupler still introduces the 6 dB inherent loss like the case of traditional fiber-optic gyroscope. Demers used a Faraday rotator and a polarizing beam splitter (PBS) to implement an optical circulator in the transceiver module based on free-space integration [2], as shown in Fig. 1(c). For this configuration, the 6 dB loss caused by the coupler is avoided because the in-plane polarization of the incoming beam after passing through the Faraday rotator twice (forward and backward) is rotated into the out-of-plane polarization and then is totally reflected by the PBS onto the receiving photodetector. However, this configuration is less advantageous for the case that the SLD source is polarization independent because the power of the split out-of-plane polarization component of the source is lost by totally reflecting at the PBS and at least 3 dB loss is introduced. Moreover, even for the transceiver module with polarization dependent SLD source, there exist the problem that the polarization of the SLD source needs to be matched to the principal axis of the PBS, which results in the complication of the integration processes and the increase of the gyroscope cost. The high signal-to-noise (SNR) obtained by decreasing the loss is advantageous for improving the sensitivity and relaxing the loss specifications of optical devices in the fiber-optic gyroscope. Currently there are lack of transceiver module configurations that meet all of the requirements of low loss, compact configuration, small size, polarization insensitivity and highly integrated form for the high sensitive and miniature fiber-optic gyroscope.

In this paper, a novel fiber-optic gyroscope transceiver module configuration based on free-space integration is proposed. Two PBS's, two Faraday rotators and two half wave plates are employed to construct a double power output configuration to utilize the output power of the SLD source fully. The 6 dB inherent loss caused by the coupler used in traditional transceiver module is eliminated so

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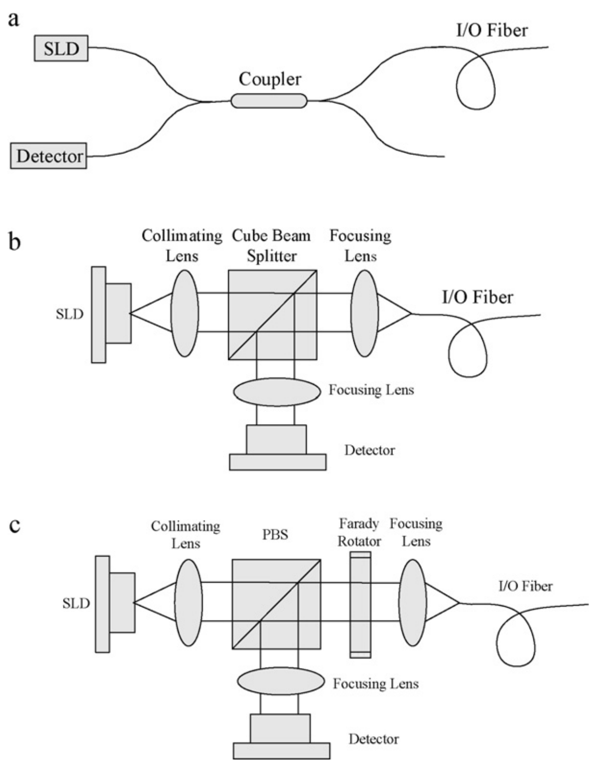

Fig. 1. Schematic diagram of the transceiver module configurations: (a) integration by fiber coupling; (b) integration by free-space coupling with a cube-beam-splitter as the coupler; (c) integration by free-space coupling with a PBS and a Faraday rotator as the circulator.

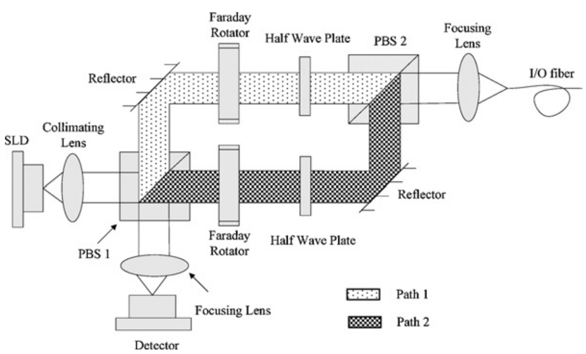

Fig. 2. Schematic diagram of the proposed transceiver module configuration.

that the higher SNR which improves the sensitivity of the gyroscope can be obtained. Moreover, the signal intensity received by the detector is insensitive to the source polarization and is independent of the power ratio of the two orthogonal polarized beams split by the PBS. Consequently, either the polarization dependent SLD or the polarization independent SLD can be used in this transceiver module, and the careful and costly polarization alignment between SLD and PBS is avoided.

2. Configuration of the proposed fiber-optic gyroscope transceiver module

Fig. 2 shows schematically the configuration of the proposed fiber-optic gyroscope transceiver module which composes a SLD source, a collimating lens, two polarization beam splitters, two Faraday rotators, two half wave plates, two focusing lenses, and a detector. All of the optical components are integrated by the free-space coupling method. The operation of the proposed transceiver module is illustrated in Fig. 3 and is described as follows. The randomly polarized beam from the SLD is split into two orthogonal, linearly, polarized components by the PBS 1 and propagate along the path 1 and path 2, respectively. The angle between the optical axis of half wave plate and the incident plane is 67.5° and the Faraday rotator rotates the polarization direction of polarized beam by 45°. As shown in Fig. 3, along path 1, the s-polarized (out-of-plane) beam reflecting at the PBS 1 proceeds from left-to-right through the Faraday rotator and half wave plate and then is rotated into p-polarized (in-plane) beam. Similarly, along path 2, the p-polarized beam transmitting at the PBS 1 is rotated into s-polarized beam after proceeding from left-to-right through the Faraday rotator and half wave plate. The two orthogonal polarization beams are combined by the PBS 2 and co-propagate through the focusing lens to be coupled into the I/O fiber. After traveling the fiber coil, the two returned orthogonal polarization beams are recombined by the I/O fiber and are subsequently separated again by the PBS 2. For the separated p-polarized beam from PBS 2 propagating along path 1 (In Fig. 3 this is the right-to-left direction.), the half wave plate rotates the beam counter clockwise by 135° and the Faraday rotator imparts a counter clockwise polarization rotation of 45° in relation to the direction of the ray of light, thus the 180° counter clockwise rotation of the beam is obtained. However, for the separated s-polarized beam from PBS 2 propagating along path 2 (In Fig. 3 this is the right-to-left direction.), the half wave plate rotates the beam clockwise by 45° and the Faraday rotator imparts a counter clockwise polarization rotation of 45° in relation to the direction of the ray of light, thus there is no net change in the polarization. Consequently, the polarization directions of the returned p-polarized and s-polarized beams separated by the PBS 2 keep unchangeable after passing through the half wave plate and Faraday rotator successively. The PBS 1 subsequently reflects the s-polarized beam and transmits the p-polarized beam onto the photodetector. It is obvious that almost all of the output power from the SLD is utilized which improves the SNR of the transceiver module. For the fiber-optic gyroscope, the relative intensity noise (RIN) of SLD is low (below −135 dB/Hz at the frequency above 20 kHz) [11], so the noise contributions of the fiber-optic gyroscope are the shot noise, Johnson noise (thermal noise). If the returning power at the detec-

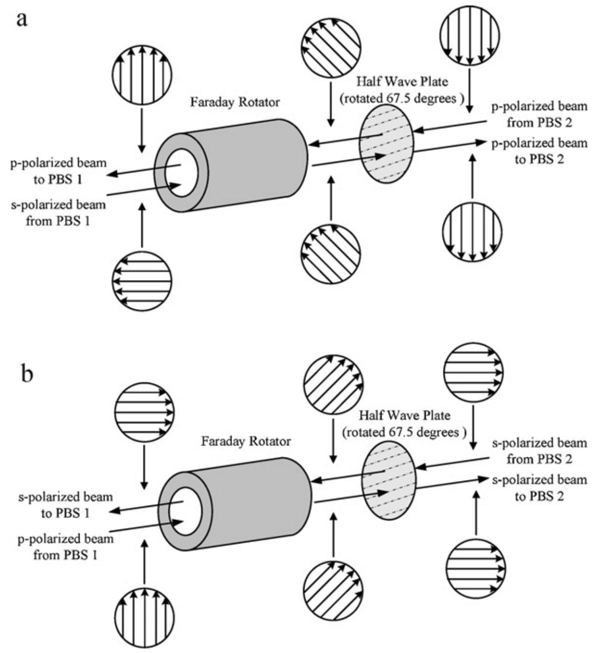

Fig. 3. Schematic diagram of the polarization evolutions along path 1 and path 2: (a) path 1 and (b) path 2.

tor is over 1 μW, the influence to SNR of the shot noise begins to become larger than that of the Johnson noise [12,13]. Therefore, for the proposed transceiver module, the higher received optical power means the higher SNR.

3. Discussions and comparison with the other fiber-optic gyroscope transceiver modules

In fact, this novel transceiver module can be regarded as a double power output configuration. The beams arriving at the photodetector include two independent parts carrying the rotation rate information of the fiber coil. Ignoring the insertion losses of the optical components and the extra losses of the gyroscope system and assuming the intensity of clockwise light wave is equal to the one of counter clockwise light wave in fiber coil, the intensity received by the detector can be written as

$$\begin{aligned} I_D &= I_P + I_S = \left|E_{\text{P-CW}} + E_{\text{P-CCW}} e^{-i\phi_s}\right|^2 + \left|E_{\text{S-CW}} + E_{\text{S-CCW}} e^{-i\phi_s}\right|^2 \\ &= \frac{1}{2}E_P^2\left|1+e^{-i\phi_s}\right|^2 + \frac{1}{2}E_S^2\left|1+e^{-i\phi_s}\right|^2 = (E_P^2+E_S^2)(1+\cos\phi_s) \\ &= E_{in}^2(1+\cos\phi_s) = I_{in}(1+\cos\phi_s) \end{aligned} \quad (1)$$

where I_P and I_S are the intensities of the two orthogonal polarization components received by the detector, respectively; I_{in} is the intensity of the SLD output beam, E_S and E_P are the amplitudes of s-polarized and p-polarized components of SLD output beam split by PBS 1, respectively. The subscripts of CW and CCW denote the clockwise and counter clockwise light waves in the fiber coil, φ_s is the Sagnac phase shift induced by inertial rotation.

Similarly, for the tradition transceiver module configuration with a polarized SLD shown in Fig. 1(a) and the transceiver module shown in Fig. 1(b), the intensity received by the detector can be written as

$$I_{\text{D-a,b}} = \frac{1}{4}I_{in}(1+\cos\phi_s) \quad (2)$$

For the transceiver module shown in Fig. 1(c), the intensity received by the detector can be written as

$$I_{\text{D-c}} = I_{in}\cos^2\theta(1+\cos\phi_s) \quad (3)$$

where θ is the angle between the polarization of SLD output beam and the principal axis of PBS. If the SLD of the transceiver module shown in Fig. 1(c) is polarization independent, the equation of the received intensity is the same with Eq. (2).

Compared with Eqs. (2) and (3), it is obvious from Eq. (1) that the gyroscope signal is strengthened and thus the detection sensitivity is improved. On the other hand, the 6 dB improvement of received optical power may reduce the requirements of SLD output power and optical devices losses in the system which means the relative increase of the life time of SLD, the reduction of the gyroscope cost and the simplification of the integration processes. In addition to the advantages caused by the high SNR, the proposed transceiver module is insensitive to the polarization state of SLD source so that either the polarization dependent SLD or the polarization independent SLD is applicable to this transceiver module. Moreover, from Eq. (1), it can also be found that the intensity received by the detector is independent of the power ratio of the p-polarized beam to the s-polarized beam split by the PBS 1, which means the careful and costly polarization alignment of the polarized SLD with respect to the principal axis of PBS necessary in the integration processes of the transceiver module shown in Fig. 1(c) is not required any longer, consequently results in the reduction of the gyroscope cost and the simplification of the integration processes too.

4. Conclusions

In summary, a novel fiber-optic gyroscope transceiver module configuration based on free-space integration is proposed and its operation is described. The high performance transceiver module with the advantages including small size, compact configuration, high SNR, polarization insensitivity, simplification of integration processes is very promising in the high sensitive and miniature fiber-optic gyroscope.

References

[1] K. Watanabe, R. Sasaki, S. Sakuma, S. Nakamura, T. Hojo, Source module with IOC and detectors for low cost fiber optic gyro, SPIE 2837 (1996) 315–323.
[2] J.R. Demers, K.K. Wong, R.T. Logan, Fiber optic gyroscope, US Patent 20090015843A1.
[3] L. Wang, Z.-Y. Liao, Y.-B. Cheng, L.-J. Zhao, J.-Q. Pan, F. Zhou, W. Wang, Monolithically integrated transceiver with novel Y-branch by bundle integrated waveguide for fiber optic gyroscope, Chin. Phys. Lett. 24 (2007) 3424–3427.
[4] Y. Kunhara, H. Nakanishi, Y. Fujimura, H. Terauchi, S. Inano, A. Ishida, A compact coaxial-type optical transceiver module using a half-transmittance photodiode for TCM optical access networks, J. Lightwave Technol. 16 (1998) 251–257.
[5] A. Ohno, Y. Ishii, S. Kamimatsuse, H. Honma, K. Maezawa, Miniature SLD module for fiber-optic-gyroscope, SPIE 1585 (1991) 431–436.
[6] P.R. Ashley, M.G. Temmen, W.M. Diffey, M. Sanghadasa, M.D. Bramson, G.A. Lindsay, A.J. Guenthner, Components for IFOG based inertial measurement units using active and passive polymer materials, SPIE 6314 (2006) J1–J11.
[7] M.L. Tsai, C.H. Ko, M.J. Chou, W.S. Lin, J.S. Chang, B.C. Tsai, Y.T. Chiou, C.H. Chu, Fiber-based BiDi transceiver module using optical subassembly with an injection molded polymer optical bench, in: Electronic Components and Technology Conference, IEEE, 2005, pp. 1629–1633.
[8] W.K. Hogan, D.P. Gaio, A novel low-cost small-form-factor transceiver module, in: Electronic Components and Technology Conference, IEEE, 2000, pp. 725–732.
[9] M. Ichino, S. Yoshikawa, H. Oomori, Y. Maeda, N. Nishiyama, T. Takayama, T. Mizue, I. Tounai, M. Nishie, Small form factor pluggable optical transceiver module with extremely low power consumption for dense wavelength division multiplexing applications, in: Electronic Components and Technology Conference, IEEE, 2005, pp. 1044–1049.
[10] M. Sanghadasa, P.R. Ashley, G.A. Lindsay, M.D. Bramson, J. Tawney, Backscatter compensation in IFOG based inertial measurement units with polymer phase modulators, J. Lightwave Technol. 27 (2009) 806–813.
[11] A. Dandridge, H.F. Taylor, Noise and correlations effects in GaAlAs broad-band sources, J. Lightwave Technol. LT-5 (1987) 689–693.
[12] C.-X. Shi, H. Kajioka, Configuration to double I-FOG output power: experimental investigation of noise performance and temperature effect, IEEE Photonics Technology Letters 8 (1996) 924–926.
[13] H. Lefevre, The Fiber-Optic Gyroscope, Artech House, Boston, MA, 1993.