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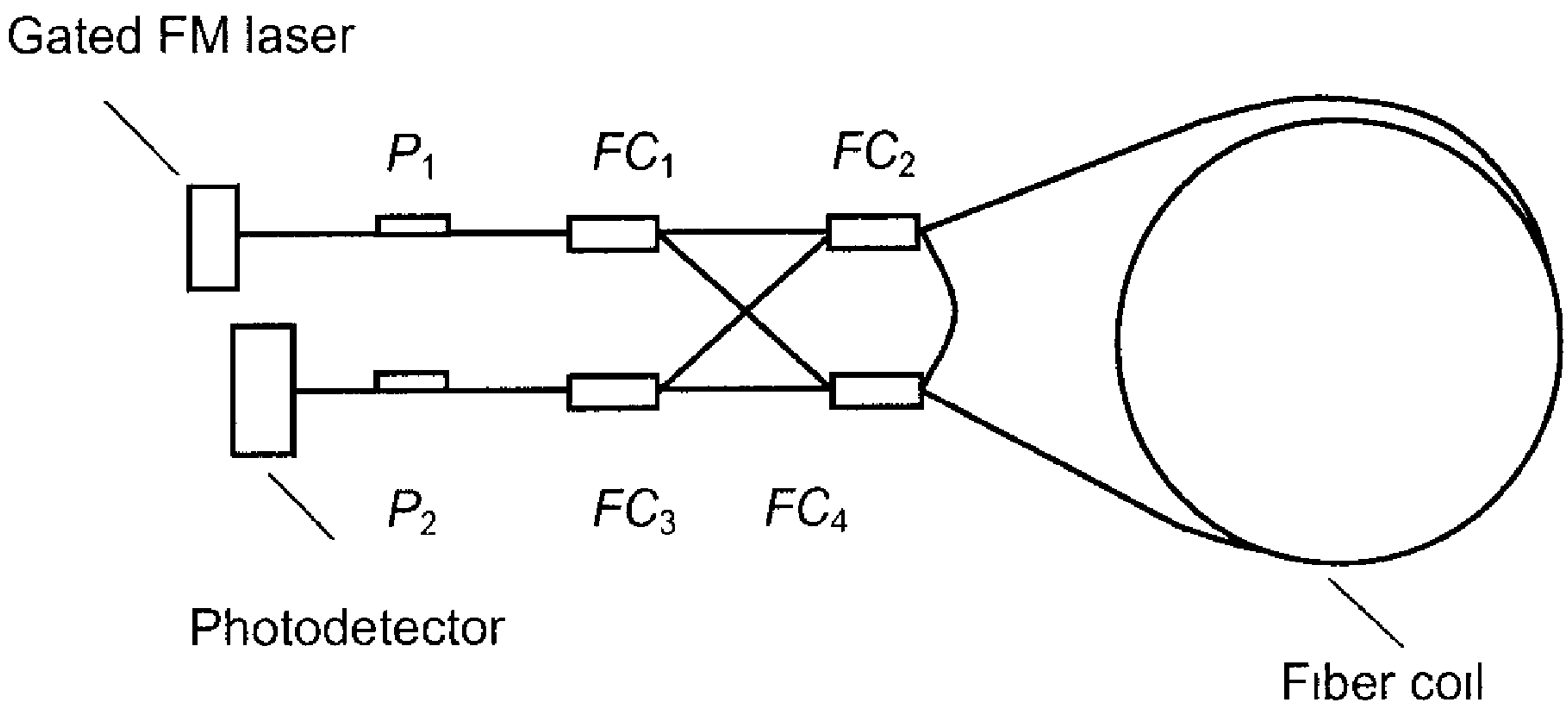
(54) Titre : GYROSCOPE DE SAGNAC DIFFERENTIEL A ONDE ENTRETENUE MODULEE EN FREQUENCE A FIBRE BIREFRINGENTE

(54) Title: DIFFERENTIAL FIBER-OPTIC FREQUENCY-MODULATED CONTINUOUS-WAVE SAGNAC GYROSCOPE



(57) Abrégé/Abstract:

Disclosed is a differential fiber-optic frequency-modulated continuous-wave (FMCW) Sagnac gyroscope for measuring rotation velocity. The gyroscope comprises a frequency-modulated laser, two fiber-optic polarizers (P_1 and P_2), two Y-type single-mode fiber-optic couplers (FC_1 and FC_3), two X-type single-mode fiber-optic couplers (FC_2 and FC_4), a single-mode fiber coil and a photodiode. The two output fibers of FC_1 and FC_3 are connected with the two input fibers of FC_2 and FC_4, the first output fibers of FC_2 and FC_4 are connected with the fiber coil, and the second output fibers of FC_2 and FC_4 are directly connected to each other to form an optical fiber shortcut, as shown in Fig. 1. The laser is driven by a gated modulation signal. The gyroscope uses the phase difference between the beat signal from the fiber coil and the beat signal from fiber shortcut to measure the rotation velocity. The advantages of this gyroscope include high accuracy, long dynamic range, good long-term stability, compact size and light weight.

Abstract

Disclosed is a differential fiber-optic frequency-modulated continuous-wave (FMCW) Sagnac gyroscope for measuring rotation velocity. The gyroscope comprises a frequency-modulated laser, two fiber-optic polarizers (P_1 and P_2), two Y-type single-mode fiber-optic couplers (FC_1 and FC_3), two X-type single-mode fiber-optic couplers (FC_2 and FC_4), a single-mode fiber coil and a photodiode. The two output fibers of FC_1 and FC_3 are connected with the two input fibers of FC_2 and FC_4, the first output fibers of FC_2 and FC_4 are connected with the fiber coil, and the second output fibers of FC_2 and FC_4 are directly connected to each other to form an optical fiber shortcut, as shown in Fig. 1. The laser is driven by a gated modulation signal. The gyroscope uses the phase difference between the beat signal from the fiber coil and the beat signal from fiber shortcut to measure the rotation velocity. The advantages of this gyroscope include high accuracy, long dynamic range, good long-term stability, compact size and light weight.

Specification

This invention relates to a differential fiber-optic frequency-modulated continuous-wave (FMCW) Sagnac gyroscope used for measuring rotation velocity. Frequency-modulated continuous-wave interference, which was originally investigated in radar, has been recently introduced in optics. Optical FMCW interference naturally produces a dynamic signal, and thus to calibrate fractional phase, distinguish phase shift direction and count the number of full periods is much easier than with the classical homodyne interference. Comparing with the traditional interferometers, optical FMCW interferometers generally can offer a higher accuracy and longer dynamic range. The application of optical FMCW interference to rotation sensing can effectively solve the problems in the conventional fiber-optic Sagnac gyroscopes, such as zero-sensitivity point, inaccurate phase calibration, ambiguous shift direction determination and π-phase shift restriction.

For an optical FMCW Sagnac gyroscope, the basic requirement is that the gyroscope should be unbalanced so that the beat signal with an appropriate frequency can be obtained. However, the unbalanced interferometer structure may introduce a new problem: there will be a nonreciprocal phase drift in the gyroscope if the environmental parameters (such as temperature) change. This nonreciprocal phase drift will significantly affect the accuracy and long-term stability of the gyroscope.

The differential fiber-optic FMCW Sagnac gyroscope exposed in this patent consists of a single-mode frequency-modulated laser, two fiber-optic polarizers (P_1 and P_2), two Y-type single-mode fiber couplers (FC_1 and FC_3), two X-type single-mode fiber couplers (FC_2 and FC_4), a single-mode fiber coil and a photodiode, as shown in Fig. 1. The laser is driven by a gated modulation signal (e.g. a gated sawtooth-wave signal). The two output fibers of FC_1 and FC_3 are connected with the two input fibers of FC_2 and FC_4, to construct the basic structure of an unbalanced fiber-optic interferometer. The first output fibers of FC_2 and FC_4 are connected with the fiber coil, and second output fibers of FC_2 and FC_4 are directly connected to each other to form an optical fiber shortcut. The two fiber-optic polarizers and an in-line polarization controller (bend and twist of a portion of fiber coil) are used to ensure that the two counter propagating beams in the fiber coil travel in the same polarization mode, so that the contrast of the beat signal can be optimized.

This gyroscope actually is a time-division multiplexed fiber-optic FMCW Sagnac gyroscope. A gated FMCW laser beam is first launched into FC_1 and split into two beams. When these beams pass through FC_2 and FC_4, they will split again. Parts of the two beams traverse the fiber coil in opposite directions, and the remainders of the two beams take the shortcut. If the delay time introduced by the fiber coil is longer than the frequency modulation period T_m but shorter than the separation of the gated wavelet ($T_m'-T_m$), the beat signal produced by the two counter-propagating beams in the fiber coil and the beat signal produced by the two counter-propagating beams in the shortcut will arrive on the photodetector at different time moments without overlapping, and therefore they can be separated by using an electric gate circuit, as shown in Fig. 2. Obviously, both beat signals contain the same nonreciprocal phase drift caused by the variation of the environmental conditions, but only the beat signal from the fiber coil contains the reciprocal Sagnac phase shift if the fiber coil is in rotation. Therefore, separating the two beat signals with an electronic gate circuit, finding the phase difference between them, the Sagnac phase shift caused by the rotation of the fiber coil can be determined.

For instance, if the frequency of the laser is modulated with a sawtooth waveform, the beat signal $I_1(t)$ from the fiber coil in a modulation period can be written as

$$I_1(t) = I_{10}\left[1 + V_1 \cos\left(\frac{2\pi\Delta\nu\nu_m OPD}{c}t + \frac{2\pi}{\lambda_0}OPD + \frac{4\pi RL\Omega}{c\lambda_0}\right)\right],$$

where I_{10} and V_1 are the average intensity and contrast of the beat signal from the fiber coil, $\Delta\nu$ is the optical frequency modulation excursion, ν_m is the modulation frequency, c is the speed of light in free space, λ_0 is the central optical wavelength in free space, and OPD is the initial optical path difference between the two interfering beams. The OPD is given by

$$OPD = n_e(l_{12} + l_{34} - l_{14} - l_{23}),$$

where n_e is the effective refractive index of the single-mode fiber, l_{12}, l_{34}, l_{14}, and l_{23} are the lengths of the linking fibers from the FC_1 to FC_2, FC_3 to FC_4, FC_1 to FC_4, and FC_2 to FC_3, respectively. Properly choosing the lengths of the linking fibers, we can get any desired initial optical path difference.

Similarly, the beat signal $I_2(t)$ from the optical fiber shortcut in a modulation period can be written as

$$I_2(t) = I_{20}\left[1 + V_2 \cos\left(\frac{2\pi\Delta\nu\nu_m OPD}{c}t + \frac{2\pi}{\lambda_0}OPD\right)\right],$$

where I_{20} and V_2 are the average intensity and contrast of the beat signal from the fiber shortcut. Obviously, the phase difference of the two beat signals $\Delta\phi$ equals

$$\Delta\phi = \frac{4\pi RL\Omega}{c\lambda_0}.$$

Hence, the rotation angular velocity of the gyroscope can be determined by

$$\Omega = \frac{c\lambda_0}{4\pi RL}\Delta\phi.$$

Note that, because $\Delta\phi$ is not relative to OPD, this gyroscope is free from the length variation of the linking fibers due to temperature change or strain.

The advantages of this gyroscope include no zero-sensitivity point, accurate phase calibration, easy shift-direction determination, no π-phase shift restriction, no nonreciprocal phase drift, and free from the frequency drift of laser source. Moreover, since there is no bulk phase modulator or bulk frequency shifter in the system, the size and weight of the gyroscope is also reduced.

The coupling ratios of the fiber couplers are determined according to the light attenuation in the fiber coil in order that the intensities of the two pulsed beat signals can be almost equal. Moreover, the fiber-optic polarizers and fiber couplers in this gyroscope can also be replaced by integrated-optic polarizers and integrated-optic couplers.

Claims

1. A differential fiber-optic FMCW Sagnac gyroscope for measuring rotation velocity, comprising a single-mode frequency-modulated laser, two fiber-optic polarizers (P_1 and P_2), two Y-type single-mode fiber couplers (FC_1 and FC_3), two X-type single-mode fiber couplers (FC_2 and FC_4), a single-mode fiber coil and a photodiode; wherein the two output fibers of FC_1 and FC_3 are connected with the two input fibers of FC_2 and FC_4, the first output fibers of FC_2 and FC_4 are connected with the fiber coil, and second output fibers of FC_2 and FC_4 are directly connected to each other as an optical fiber shortcut;
2. A gyroscope as defined in claim 1, wherein said laser is driven by a gated modulation signal, the frequency modulation period T_m of said gated modulation signal is shorter than the delay time introduced by said fiber coil, and the separation of said gated wavelet ($T_m'-T_m$) is longer than the delay time introduced by said fiber coil; wherein the beat signal produced by the two counter-propagating beams in said fiber coil and the beat signal produced by the two counter-propagating beams in said fiber shortcut are detected by said photodetector and separated by using an electric gate circuit, and the phase difference between these two beat signals is measured to determine the rotation velocity;
3. A gyroscope as defined in claim 1 or claim 2, wherein said single-mode frequency-modulated laser can be at least a single-mode semiconductor laser;
4. A gyroscope as defined in claim 1 or claim 2 or claim 3, wherein said single-mode frequency-modulated laser includes coupling lenses, a temperature control system or frequency stabilization system, and a current driving circuit;
5. A gyroscope as defined in claim 1 or claim 2 or claim 3, wherein said gated modulation signal can be at least a gated sawtooth-wave signal, a gated triangular-wave signal, a gated sinusoidal-wave signal, or a gated rectangular-wave signal;
6. A gyroscope as defined in claim 1 or claim 2, wherein said fiber-optic polarizers and fiber-optic couplers can be integrated-optic polarizers and integrated-optic couplers;
7. A gyroscope as defined in claim 1 or claim 2, wherein said photodetector can be at least a p-i-n photodiode or avalanche photodiode;
8. A gyroscope as defined in claim 1 or claim 2, including a signal generation and processing electric circuit or a microcomputer-controlled digital signal generation and processing system;
9. A gyroscope as defined in claim 1 or claim 2, wherein the rotation velocity is determined by comparing the phase difference between said two beat signals;
10. A gyroscope as defined in claim 1 or claim 2, wherein the rotation velocity is determined by comparing the phase difference between the beat signal from the said fiber coil and a standard reference signal of the same frequency;

11. A gyroscope as defined in claim 1 or claim 2 or claim 9 or claim 10, wherein the phase difference of said two signals can be measured at least by comparing the phase difference of their most intensive harmonics, or by comparing the relative intensity of said two signals at a certain time moment in a modulation period;
12. A gyroscope as defined in claim 1 or claim 2, wherein said fiber couplers and said fiber coil can be single-mode polarization-maintaining fiber couplers and single-mode birefringent fiber coil.

Drawings

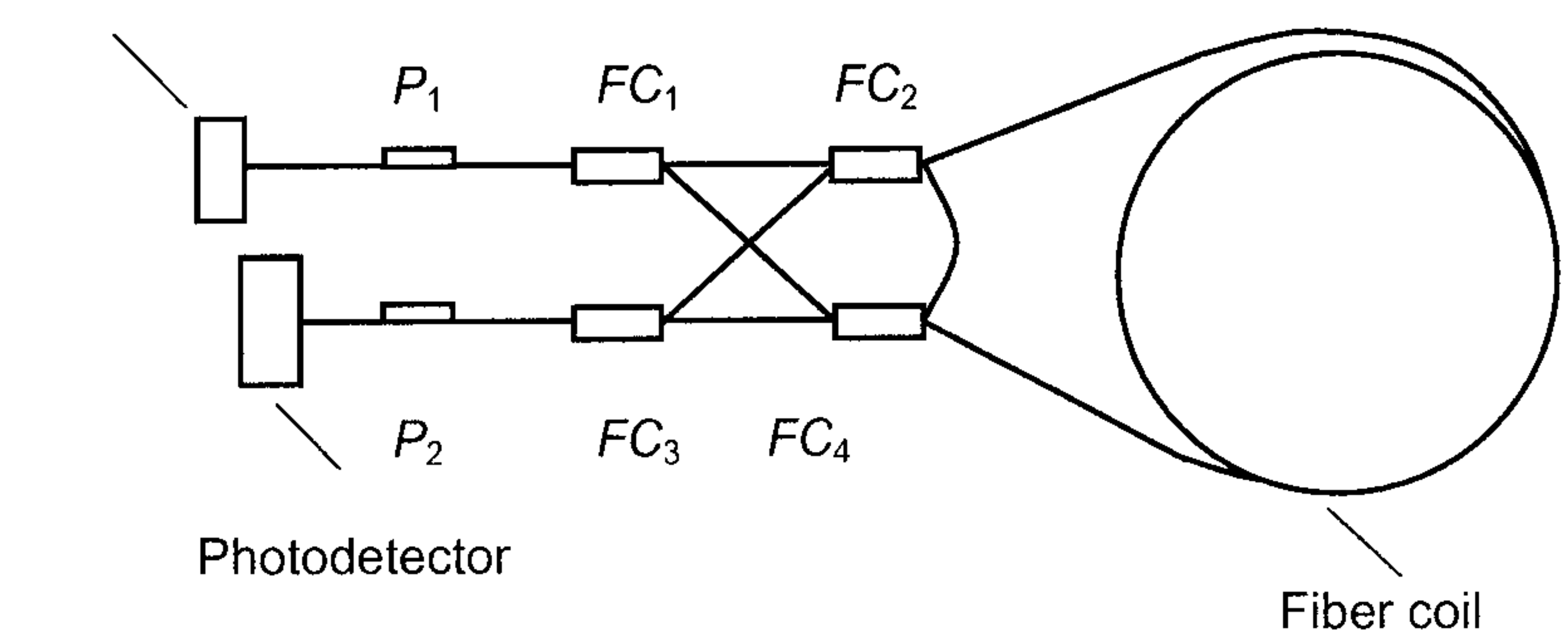
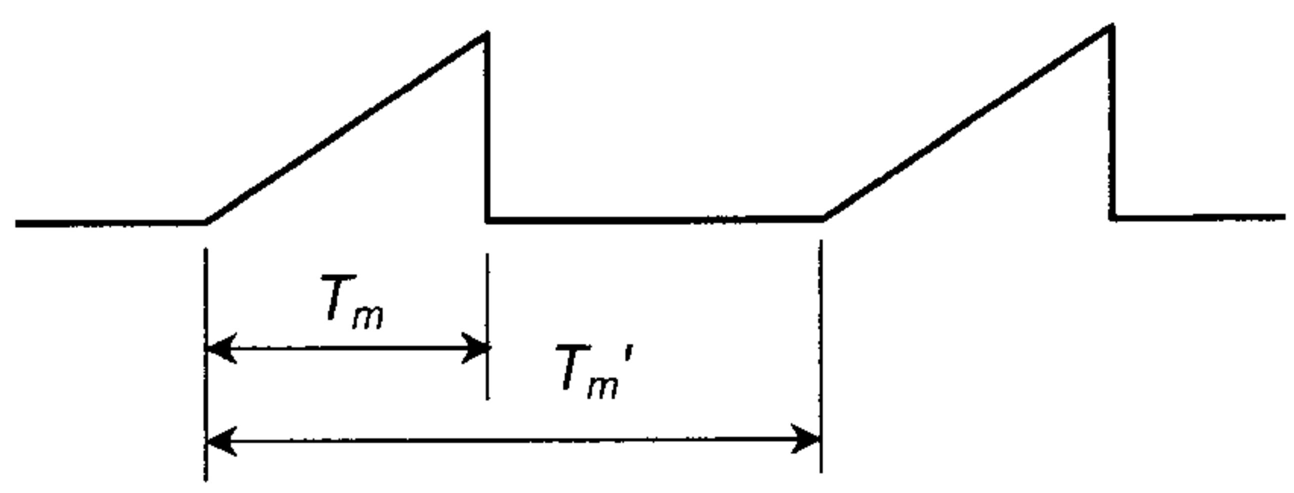
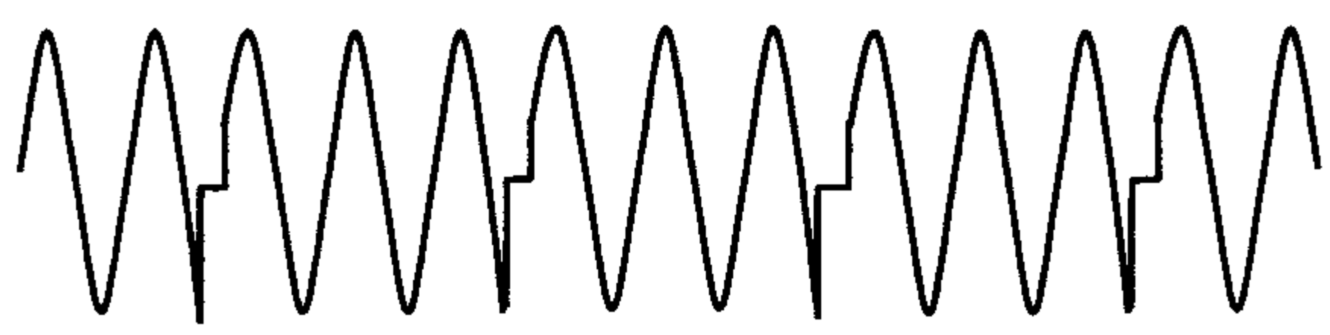


Fig.1

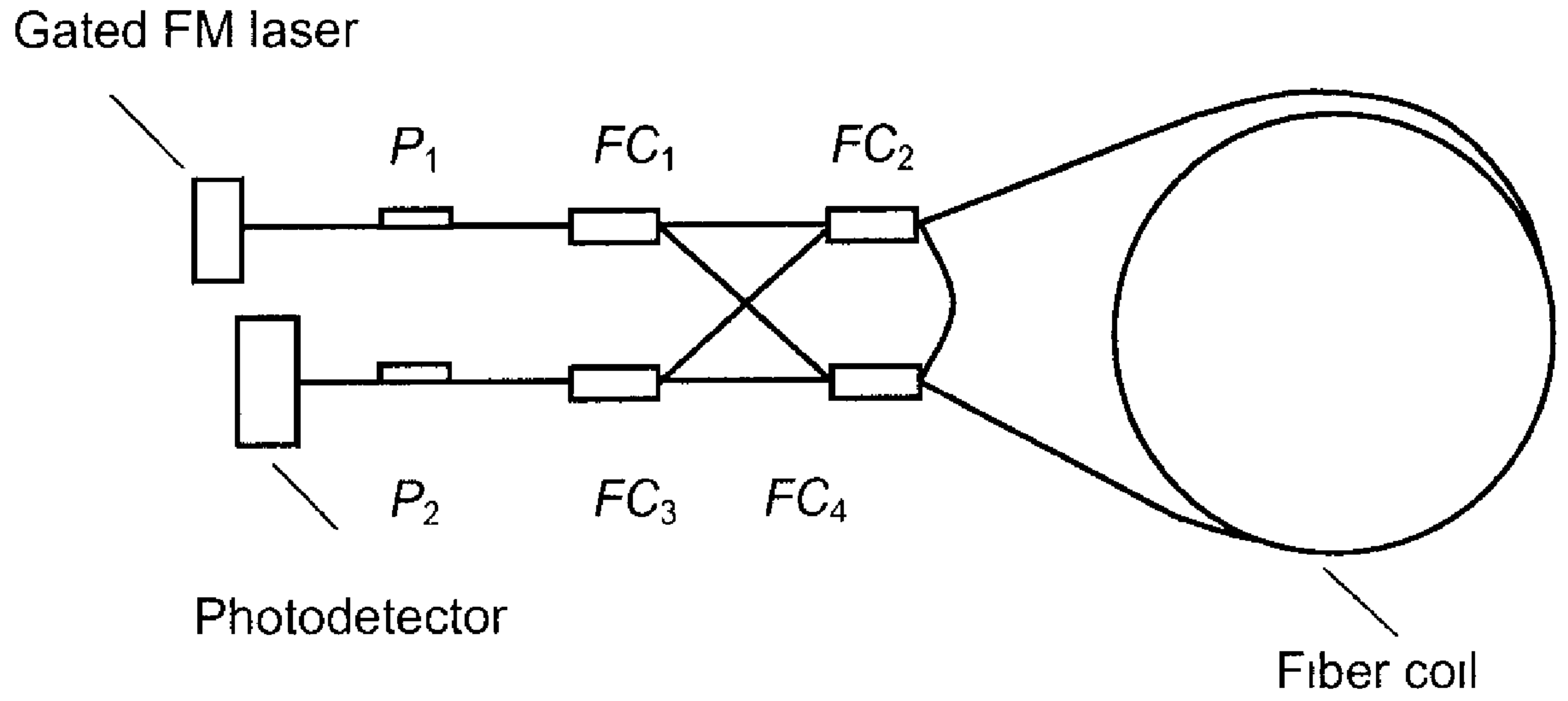


(a) Waveform of the modulation signal.



(b) Waveform of the mixed signal.

Fig. 2


Gated FM laser
P_1
FC_1
FC_2
P_2
FC_3
FC_4
Photodetector
Fiber coil