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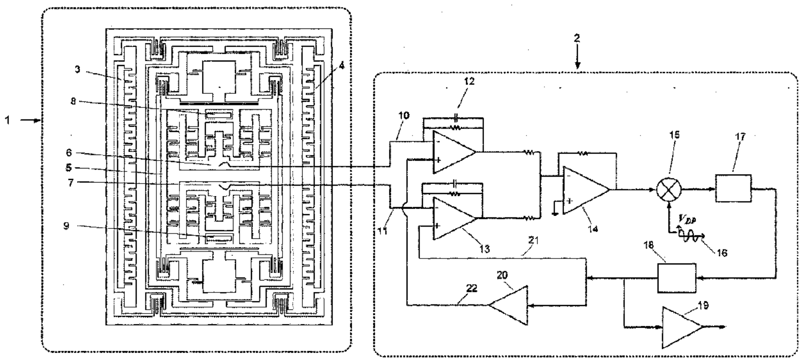

FIG. 1

(57) Abstract: The invention relates to provide a method for suppression of the g-sensitivity of MEMS gyroscope (1) by keeping the movable sense frame of the gyroscope stationary irrespective to the external accelerations with the aid of closed-loop feedback circuit (2).

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DESCRIPTION

METHOD FOR SUPPRESION OF G-SENSITIVITY OF MEMS GYROSCOPE

Related Field of the Invention

The invention relates to provide a method for suppression of the linear-acceleration-sensitivity of MEMS gyroscope by keeping the movable sense frame of the gyroscope quasi-stationary, irrespective to the external accelerations with the aid of closed-loop feedback circuit.

Background of the Invention (Prior Art)

The adaptation of the IC processing technology for creating controllable, mechanical and movable microstructures in the past few decades has made the major contribution to the evolution of today's high-technology systems. The rapid growth of the micromachining technologies has generated various kinds of developments in many diverse fields, ranging from consumer products to communication, from inertial navigation systems to medicine and bioengineering. In today's technology, many of the MEMS sensors have presented better performances than their macro scale counterparts. Similarly, MEMS gyroscopes are expected to take the place of the ring laser and fiber optic gyroscopes in many applications because of their high reliability, promising performance, small size, and low cost in the near future [1]. MEMS gyroscopes are widely used in automotive roll-over prevention, airbag systems, image stabilization, and they have many other potential applications.

The operation of the MEMS vibratory gyroscopes relies on the Coriolis coupling, which enables the transfer of the energy from the drive to sense mode in the presence of an angular rotation. With the advance development in the gyroscope performance characteristics including the bias instability, resolution and bandwidth, the environmental effects such as vibration and acceleration acting on the gyroscope have a prominent impact on the reliability and robustness of the gyroscope [2], [3]. Considering the application areas of high performance MEMS inertial sensors, these sensors are usually exposed to various vibrations and acceleration during the operation. These effects causes an output error, namely 'acceleration sensitivity' or 'acceleration output'.

In everyday and field applications, the outputs of all MEMS gyroscopes are affected by external accelerations, partly due to their design and partly due to the fabrication imperfections. The effect of acceleration on the gyroscope output can be seen in the different forms, the most significant ones are usually sensitivity to linear acceleration (or g sensitivity) and vibration rectification (or g^2 sensitivity). Since most of the gyroscopes are subjected to the Earth's 1 g field of gravity in the application, the sensitivity acceleration exhibits one of the largest error sources [4].

The high frequency acceleration or vibration outputs are difficult to predict and very hard to compensate using electronics; thus, the compensation of the vibration rectification error is usually done by improving the mechanical design of gyroscope rather than the control electronics. A common method to reduce the effect of the external acceleration or vibration is to use the tuning-fork type vibrating gyroscopes (TFG) which are believed to be insensitive to the common mode signals such as linear acceleration because these signals are mitigated by the differential reading of the sense mode signals coming from the two differentially-connected masses [5], [2], [6], [7]. However, it has been found that tuning fork type gyroscopes could still experience an output error caused by applying the linear acceleration along the sense axis to the gyros [8].

Implementing a micro-mechanical shock absorber under the sensor structure is another method to eliminate the effect of random high-frequency accelerations or vibrations [9]. Although this method provides a solution for the vibration sensitivity of a gyroscope, it does not eliminate the effects of static or low frequency accelerations.

Acceleration sensitivity of the gyroscope can also be improved by calibrating the gyroscope output with the aid of an additional external accelerometer; however, the amount of the measured acceleration cannot always be the acceleration sensed by the gyroscope due to the difference in the physical locations of both sensors [4].

Quadruple mass gyroscope design is also implemented to make the sensor immune to the external shock and vibration [10]. However, it is hard to realize a higher performance due to the complex structure of four-mass gyroscopes.

Brief Description of the Invention:

The present invention provides a method for suppression of the g-sensitivity of MEMS gyroscope by keeping the movable sense frame of the gyroscope stationary irrespective to the external accelerations with the aid of closed-loop feedback circuit. The proposed methods utilize the amplitude difference of sustained residual quadrature signals exist on the differential sense mode electrodes to detect the static acceleration acting on the sense axis of the gyroscope.

In the absence of the external acceleration, the average gap spacing of the positive and negative sense mode electrodes are equal, resulting in the out of phase quadrature signals with the same amplitudes. However, when the net force resulting from an applied quasi-static acceleration on the movable sense frame is different than zero, the capacitive gap between the differential sense-mode electrodes decreases on one side and increases on the other. This shift causes a variation at the amplitudes of the quadrature signals on the differential sense-mode electrodes, i.e., the amplitude of the quadrature signal increases (or decreases) with a decreasing (or increasing) capacitive gap under the condition of an applied static acceleration condition compared to the case when there is no acceleration. As a result, the sum of the positive and negative AC quadrature signals gives nonzero output showing that an external acceleration act on the sense axis of the gyroscope.

Definition of the Figures

In order to explain the present invention in more detail, the following figures have been prepared and attached to the description. The list and the definition of the figures are given below.

FIGURES 1, 2, 3, and 4 describe the three different embodiments of the method presented in this invention.

FIGURE 1	shows a MEMS gyroscope with a closed-loop acceleration cancellation control circuit.
FIGURE 2	shows a MEMS gyroscope with a closed-loop acceleration cancellation control circuit.
FIGURE 3	shows a MEMS gyroscope with a closed-loop acceleration cancellation control circuit and dedicated acceleration cancellation electrode pairs.
FIGURE 4A	shows a movable sense of a MEMS gyroscope in the absence of a static acceleration
FIGURE 4B	shows a movable sense frame (5) of a MEMS gyroscope (1) under a static acceleration.

Definition of the Elements (Features/Components/Parts) on the Figures

The definition of the features/components/parts that are covered in the figures that are prepared in order to explain the present invention better are separately numbered and given below.

1. MEMS gyroscope
2. Acceleration cancellation circuit
3. Drive mode actuation electrodes
4. Drive mode sensing electrodes
5. Movable sense mode frame
6. Positive sense mode electrodes
7. Negative sense mode electrodes
8. Positive force-feedback electrode
9. Negative force-feedback electrode
10. Positive sense mode channel output signal
11. Negative sense mode channel output signal
12. Preamplifier of positive sense mode channel output
13. Preamplifier of negative sense mode channel output
14. Summing amplifier
15. Demodulator
16. Drive mode channel output signal
17. Low pass filter
18. Controller
19. Buffer
20. Inverting Amplifier
21. Positive feedback voltage
22. Negative feedback voltage
23. Positive acceleration cancellation electrode
24. Negative acceleration cancellation electrode
25. Average capacitive gap positive sense mode electrodes
26. Average capacitive gap negative sense mode electrodes
27. Nonzero static acceleration

Detailed Description of the Invention

The present invention aims to improve the static acceleration sensitivity of MEMS gyroscopes (1) with aid of a closed-loop feedback circuit (2), without requiring any complex change in the mechanical structure of the gyroscope (1). The invention is described by a few exemplary embodiments, although the scope and spirit of the invention is not limited to the particular forms disclosed by these embodiments.

The methods described in this invention are based on the acceleration cancellation circuit (2). The function of the proposed circuits (2) is to generate a feedback voltage (21, 22) applied to the positive force-feedback electrode (8) and negative force-feedback electrode (9) located on the sense frame to stop the motion of the movable sense frame caused by the static acceleration.

In this invention, the different versions of the closed loop feedback mechanisms are presented to suppress the g-sensitivity of the MEMS gyroscope (1) are included. These methods are followings:

Method-1

In this method, the acceleration force acting on the sense axis is balanced by generating a DC force on the sense mode electrodes (6, 7). Normally, the function of the sense mode electrodes (6, 7) is to convert the sense mode displacement to the output current. In other words, these electrodes (6, 7) are used to detect the sense mode output current. However, in this method, the sense mode electrodes (6, 7) are used for both sensing and actuation purposes. This method does not require any change in the mechanical structure of the MEMS gyroscope (1).

The static acceleration acting on the movable sense frame is sensed by comparing the amplitudes of the out of phase quadrature signals generated on the differential sense mode electrodes (6, 7) using a summing amplifier (14). The output of the summing amplifier (14) is demodulated with the drive mode channel output signal (16). The output of the demodulator passes through a low pass filter (17), and the output of the low pass filter (17) is fed to the controller op-amp (18). The controller op-amp (18) generates a DC voltage proportional with the amplitude of the static acceleration. The feedback voltages (21, 22) are connected to the non-inverting inputs of the sense mode preamplifiers (12, 13) differentially. Any voltage change in the non-inverting inputs of the sense mode preamplifiers (12, 13) alters the DC voltages on the differential sense mode electrodes (6, 7). If the DC voltages on the differential sense mode electrodes (6, 7) are not equal, a DC force is generated on the movable sense frame in the opposite direction of the static acceleration force. As a result, the movable sense frame is kept stationary under an external acceleration, suppressing the g-sensitivity of the gyroscope bias.

Method-2

In this method, the acceleration force acting on the sense axis is balanced by generating a DC force on the force-feedback electrodes (8, 9). Normally, the function of the force-feedback electrodes (8, 9) is to stop the movement of the proof mass caused by Coriolis force. However, in this method, the force-feedback electrodes (8, 9) are used to generate both AC force at the drive frequency and DC voltage. This method does not require any change in the mechanical structure of the MEMS gyroscope (1).

The static acceleration acting on the movable sense frame is sensed by comparing the amplitudes of the out of phase quadrature signals generated on the differential sense mode electrodes (6, 7) using a summing amplifier (14). The output of the summing amplifier (14) is demodulated with the drive mode output signal (16). The output of the demodulator (15) passes through a low pass filter (17), and the output of the low pass filter (17) is fed to the controller op-amp. The controller op-amp (18) generates a DC voltage proportional with the amplitude of the static acceleration. The feedback voltages (21, 22) are fed to the force-feedback electrodes (8, 9) differentially. If the DC voltages on the differential force feedback electrodes (8, 9) are not equal, a DC force is generated on the movable sense mode frame (5) in the opposite direction of the static acceleration force. As a result, the movable sense frame (5) is kept stationary under an external acceleration, suppressing the g-sensitivity of the gyroscope bias.

Method-3

In this method, the acceleration force acting on the sense axis is balanced by generating a DC force on the dedicated acceleration cancellation electrodes (23, 24). The function of these electrodes (23, 24) is to generate DC force on the movable sense frame (5) in the opposite direction of the static acceleration force. This method requires a small change in the mechanical structure of the MEMS gyroscope (1).

The static acceleration acting on the movable sense frame (5) is sensed by comparing the amplitudes of the out of phase quadrature signals generated on the differential sense mode electrodes (6, 7) using a summing amplifier (14). The output of the summing amplifier (14) is demodulated with the drive mode output signal (10, 11). The output of the demodulator passes through a low pass filter (17), and the output of the low pass filter (17) is fed to the controller op-amp (18). The controller op-amp (18) generates a DC voltage proportional with the amplitude of the static acceleration. The feedback voltages (21, 22) are fed to the differential acceleration cancellation electrodes (23, 24). If the DC voltages on the differential acceleration cancellation electrodes (23, 24) are not equal, a DC force is generated on the movable sense mode frame (5) in the opposite direction of the static acceleration force. As a result, the movable sense frame (5) is kept stationary under an external acceleration, suppressing the g-sensitivity of the gyroscope bias.

The explanations of the figures for present invention are given below;

Figure 1 shows a MEMS gyroscope (1) with a closed-loop acceleration cancellation control circuit (2) applying feedback voltage (21, 22) to the sense mode electrodes (6, 7). The MEMS gyroscope (1) includes drive actuation electrodes (3), drive sensing electrodes (4), movable sense mode frame (5), positive sense mode electrodes (6), negative sense mode electrodes (7), positive force-feedback electrode (8) and negative force-feedback electrode (9). The closed-loop acceleration cancellation circuit (2) is composed of sense mode preamplifier (12) for positive sense mode channel output signal (10), sense mode preamplifier (13) for negative sense mode channel output signal (11), summing amplifier (14), demodulator (15), low-pass filter (17), controller stage (18), buffer amplifier (19), inverting amplifier (20). In the MEMS gyroscope (1), the positive sense mode electrodes (6) generate quadrature based positive sense mode channel output signal (10), and the negative sense mode electrodes (7) generate quadrature based negative sense mode channel output signal (11). The positive sense mode channel output signal (10) is converted to the positive sense mode channel output voltage via the preamplifier stage (12). Similarly, the negative sense mode channel output signal (11) is converted to the negative sense mode channel output voltage via the preamplifier stage (13). A summing amplifier (14) sums the out of phase quadrature signals. The output of the summing amplifier (14) is modulated with the drive mode channel output signal (16) at a demodulator (15). The output of the demodulator (15) passes through a low pass filter (17). The output of the low pass filter (17) gives a measure of the static acceleration acting on movable sense frame (5). The output of the low pass filter (17) is fed to the controller stage (18). The controller stage (18) generates a feedback voltage (21) to keep the movable sense frame (5) of the MEMS gyroscope (1) stationary irrespective to the external acceleration. The generated feedback voltage (21) depends on the amplitude of the static acceleration acting on the movable sense frame (5) of the MEMS gyroscope (1). The feedback voltage (21) is inverted using an inverting amplifier (20). The feedback voltage (21) is connected to the non-inverting input of the sense mode preamplifier (11). The inverted feedback voltage (22) is connected to the non-inverting input of the sense mode preamplifier (12). The voltage change in the non-inverting inputs of the sense mode preamplifiers (12, 13) alters DC voltage on the positive sense mode electrodes (6) and negative sense mode electrodes (7). If DC voltages the positive sense mode electrodes (6) and negative sense mode electrodes (7) are different, a nonzero DC force is generated on the movable sense frame (5) in the opposite direction of the static acceleration force. The generated DC force compensates the effect of the static acceleration on the movable sense frame (5). The output (21) of the controller stage (18) also passes through a buffer (19). The output of the buffer (19) gives information about the amplitude of the acceleration.

Figure 2 shows a MEMS gyroscope (1) with a closed-loop acceleration cancellation control circuit (2) applying feedback voltage (21, 22) to force-feedback electrodes (6, 7). The MEMS gyroscope (1) includes drive actuation electrodes (3), drive sensing electrodes (4), movable sense mode frame (5), positive sense mode electrodes (6), negative sense mode electrodes (7), positive force-feedback electrode (8) and negative force-feedback electrode (9). The closed-loop acceleration cancellation circuit (2) is composed of sense mode preamplifier (12) for positive sense mode channel output signal (10), sense mode preamplifier (13) for negative sense mode channel output signal (11), summing amplifier (14), demodulator (15), low-pass filter (17), controller stage (18), buffer amplifier (19), inverting amplifier (20). In the MEMS gyroscope (1), the positive sense mode electrodes (6) generate quadrature based positive sense mode channel output signal (10), and the negative sense mode electrodes (7) generate quadrature based negative sense mode channel output signal (11). The positive sense mode channel output signal (10) is converted to the positive sense mode channel output voltage via the preamplifier stage (12). Similarly, the negative sense mode channel output current (11) is converted to the negative sense mode channel output voltage via the preamplifier stage (13). A summing amplifier (14) sums the out of phase quadrature signals. The output of the summing amplifier (14) is modulated with the drive mode channel output signal (16) at a demodulator (15). The output of the demodulator (15) passes through a low pass filter (17). The output of the low pass filter (17) gives a measure of the static acceleration acting on movable sense frame (5). The output of the low pass filter (17) is fed to the controller stage (18). The controller stage (18) generates a feedback voltage (21) to keep the movable sense frame (5) of the MEMS gyroscope (1) stationary irrespective to the external acceleration. The generated feedback voltage (21) depends on the amplitude of the static acceleration acting on the movable sense frame (5) of the MEMS gyroscope (1). The feedback voltage (21) is inverted using an inverting amplifier (20). The feedback voltage (21) is connected to positive force-feedback electrode (21). The inverted feedback voltage (22) is connected to the negative force-feedback electrode (9). If DC voltages on the positive force-feedback electrode (8) and negative force-feedback electrode (9) are different, a nonzero DC force is generated on the movable sense frame (5) in the opposite direction of the static acceleration force. The generated DC force compensates the effect of the static acceleration on the movable sense frame (5). The output of the controller stage (18) also passes through a buffer (19). The output of the buffer (19) gives information about the amplitude of the acceleration.

Figure 3 shows a MEMS gyroscope (1) with a closed-loop acceleration cancellation control circuit (2) applying feedback voltage to force-feedback electrodes (8, 9). The MEMS gyroscope (1) includes drive actuation electrodes (3), drive sensing electrodes (4), movable sense mode frame (5), positive sense mode electrodes (6), negative sense mode electrodes (7), positive force-feedback electrode (8), negative force-feedback electrode (9), positive acceleration cancellation electrode (23), and negative acceleration cancellation electrode (24). The closed-loop acceleration cancellation circuit (2) is composed of sense mode preamplifier (12) for positive sense mode channel output signal (10), sense mode preamplifier (13) for negative sense mode channel output signal (11), summing amplifier (14), demodulator (15), low-pass filter (17), controller stage (18), buffer amplifier (19), inverting amplifier (20). In the MEMS gyroscope (1), the positive sense mode electrodes (6) generate quadrature based positive sense mode channel output current (10), and the negative sense mode electrodes (7) generate quadrature based negative sense mode channel output current (11). The positive sense mode channel output current (10) is converted to the positive sense mode channel output voltage via the preamplifier stage (12). Similarly, the negative sense mode channel output current (10) is converted to the negative sense mode channel output voltage via the preamplifier stage (13). A summing amplifier (14) sums the out of phase quadrature signals. The output of the summing amplifier is modulated with the drive mode channel output signal (16) at a demodulator (15). The output of the demodulator (15) passes through a low pass filter (17). The output of the low pass filter (17) gives a measure of the static acceleration acting on movable sense frame (5). The output of the low pass filter (17) is fed to the controller stage (18). The controller stage

(18) generates a feedback voltage (21) to keep the movable sense frame (5) of the MEMS gyroscope (1) stationary irrespective to the external acceleration. The generated feedback voltage (21) depends on the amplitude of the static acceleration acting on the movable sense frame (5) of the MEMS gyroscope (1). The feedback voltage (21) is inverted using an inverting amplifier (20). The feedback voltage (21) is connected to positive acceleration cancellation electrodes (23). The inverted feedback voltage (22) is connected to the negative acceleration cancellation electrodes (24). If DC voltages on the positive acceleration cancellation electrodes (22) and negative acceleration cancellation electrodes (24) are different, a nonzero DC force is generated on the movable sense frame (5) in the opposite direction of the static acceleration force. The generated DC force compensates the effect of the static acceleration on the movable sense frame (5). The output of the controller stage (18) also passes through a buffer (19). The output of the buffer (19) gives information about the amplitude of the acceleration.

Figure 4A shows the movable sense frame (5) in the absence of the static acceleration. In the absence of the external acceleration, the average gap spacing (25) of positive sense mode electrodes (6) and the average gap spacing (26) of the negative sense mode electrodes (7) are equal. The positive sense mode electrodes (6) generates positive AC quadrature signal (10), and the negative sense mode electrodes (7) generates negative AC quadrature signal (11). The amplitudes of the positive AC quadrature signal (10) and negative AC quadrature signal (11) are equal when there is no acceleration.

Figure 4B shows the movable sense frame (5) under a static acceleration (27). Under a static acceleration (27), the average gap spacing of positive sense mode electrodes (6) and the average gap spacing of the negative sense mode electrodes (7) are not equal. The positive sense mode electrodes (6) generates positive AC quadrature signal (10), and the negative sense mode electrodes (7) generates negative AC quadrature signal (11). The amplitudes of the positive AC quadrature signal (10) and negative AC quadrature signal (11) gets different under a static acceleration (27).

The implementation of the inventive system, suppression during operation with the aid of the feedback circuit of the MEMS gyroscope's (1) sensitivity to static acceleration and stopping the movement formed on the microstructure due to the acceleration feedback is obtained. Also feedback circuit can be easily applied to the MEMS gyroscope with different microstructures.

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CLAIMS

1. Method for suppression of g-sensitivity of MEMS gyroscope comprising;

- a MEMS gyroscope (1) includes drive actuation electrodes (3), drive sensing electrodes (4), movable sense mode frame (5), positive sense mode electrodes (6), negative sense mode electrodes (7), positive force-feedback electrode (8) and negative force-feedback electrode (9),
- a closed-loop acceleration cancellation circuit (2) with MEMS gyroscope (1) applying feedback voltage (21, 22) to the sense mode electrodes (6,7),
- a movable sense frame (5), the static acceleration acting on and is sensed by comparing the amplitudes of the out of phase quadrature signals generated on the differential sense mode electrodes (6, 7) using a summing amplifier (14),
- a summing amplifier (14) is demodulated with the drive mode output signal (16),
- a demodulator (15), the output of the summing amplifier (14) is modulated with the drive mode channel output signal (16) at and passes through a low pass filter (17),
- a low pass filter (17) gives a measure of the static acceleration acting on movable sense frame (5) and is fed to the controller stage (18),
- a controller stage (18) generates a feedback voltage (21) to keep the movable sense frame (5) of the MEMS gyroscope (1) stationary irrespective to the external acceleration,
- a buffer (19), the output of the controller stage (18) also passes through and gives information about the amplitude of the acceleration,
- an inverting amplifier (20) for inverting the feedback voltage (21).

2. Method for suppression of g-sensitivity of MEMS gyroscope characterized in that in Method 1; the acceleration force acting on the sense axis is balanced by generating a DC force on the sense mode electrodes (6, 7) and sense mode electrodes are used for both sensing and actuation purposes.

3. Method for suppression of g-sensitivity of MEMS gyroscope characterized in that as in claim 2; in Method 1, the feedback voltages (21, 22) are connected to the non-inverting inputs of the sense mode preamplifiers (12, 13) differentially.

4. Method for suppression of g-sensitivity of MEMS gyroscope characterized in that as in claim 2 and 3; in Method 1, any voltage change in the non-inverting inputs of the sense mode preamplifiers (12, 13) alters the DC voltages on the differential sense mode electrodes (6, 7).

5. Method for suppression of g-sensitivity of MEMS gyroscope characterized in that in Method 2; the acceleration force acting on the sense axis is balanced by generating a DC force on the force-feedback electrodes (8, 9) and the force-feedback electrodes (8, 9) are used to generate both AC force at the drive frequency and DC voltage.

6. Method for suppression of g-sensitivity of MEMS gyroscope characterized in that as in claim 5; in Method 2, the feedback voltages (21, 22) are fed to the force-feedback electrodes (8, 9) differentially.

7. Method for suppression of g-sensitivity of MEMS gyroscope characterized in that as in claim 5 and 6; in Method 2, if the DC voltages on the differential force feedback electrodes (8, 9) are not equal, a DC force is generated on the movable sense mode frame (5) in the opposite direction of the static acceleration force.

8. Method for suppression of g-sensitivity of MEMS gyroscope characterized in that in Method 3; the acceleration force acting on the sense axis is balanced by generating a DC force on the dedicated acceleration cancellation electrodes (23, 24) and electrodes are used to generate DC force on the movable sense frame (5) in the opposite direction of the static acceleration force.

9. Method for suppression of g-sensitivity of MEMS gyroscope characterized in that as in claim 8; in Method 3, the feedback voltages (21, 22) are fed to the differential acceleration cancellation electrodes (23, 24).

10. Method for suppression of g-sensitivity of MEMS gyroscope characterized in that as claim 8 and 9; in Method 2, if the DC voltages on the differential acceleration cancellation electrodes (23, 24) are not equal, a DC force is generated on the movable sense mode frame (5) in the opposite direction of the static acceleration force.

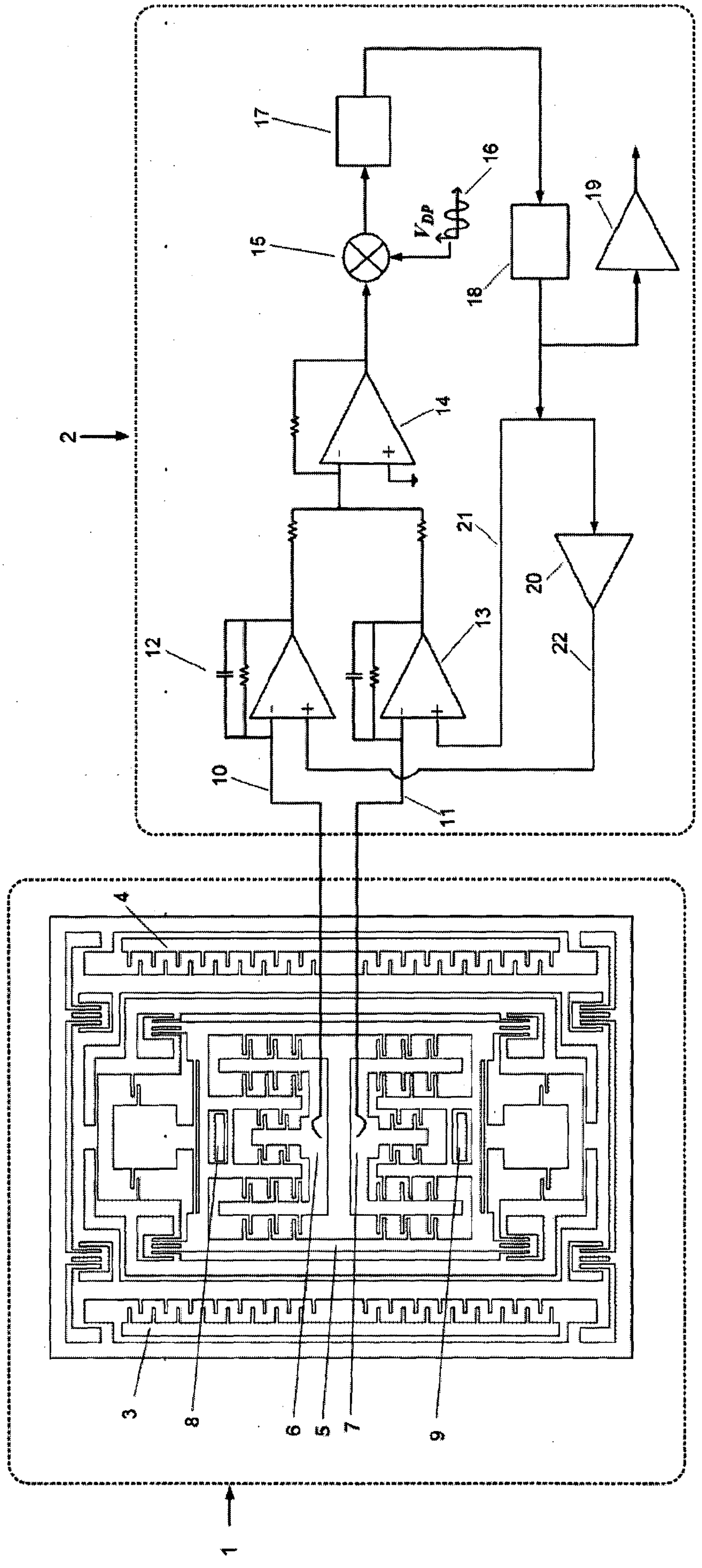

FIG. 1

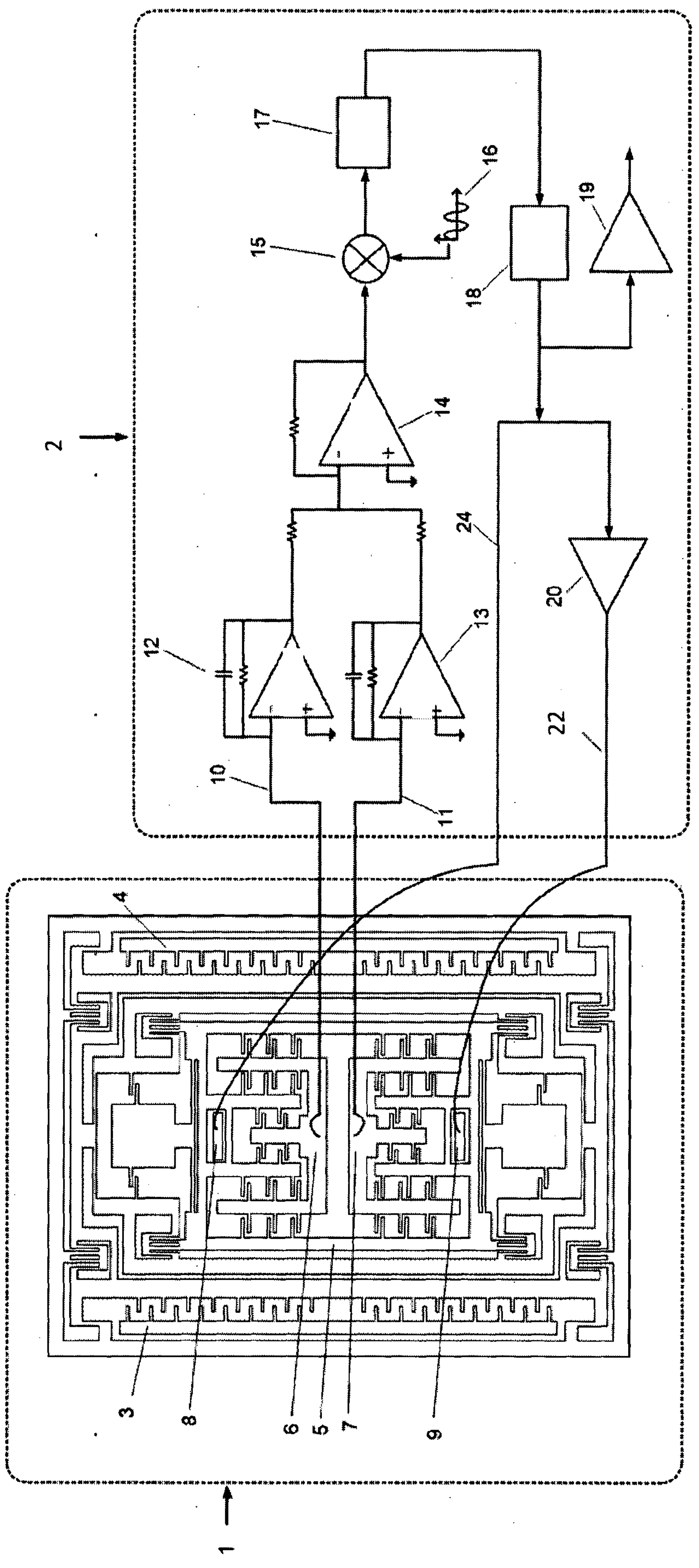

FIG. 2

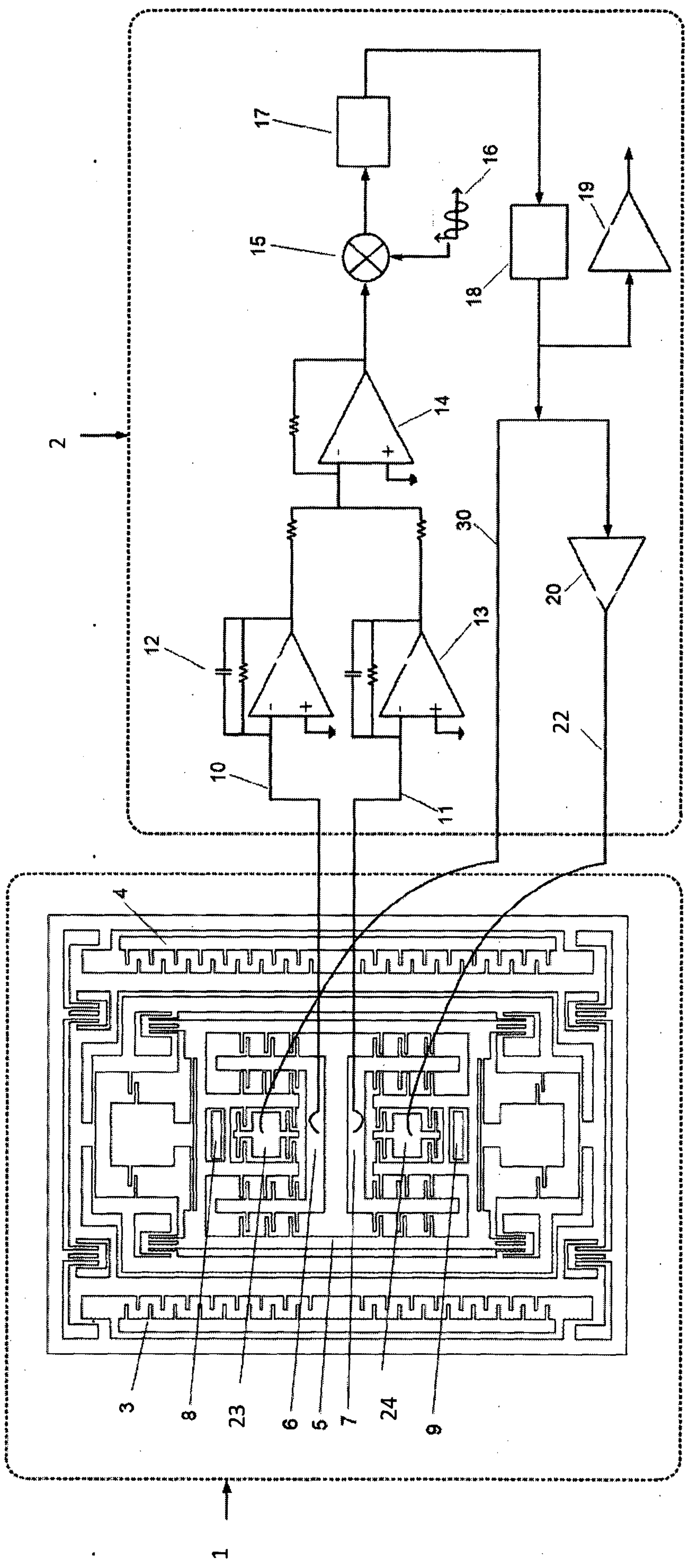

FIG. 3

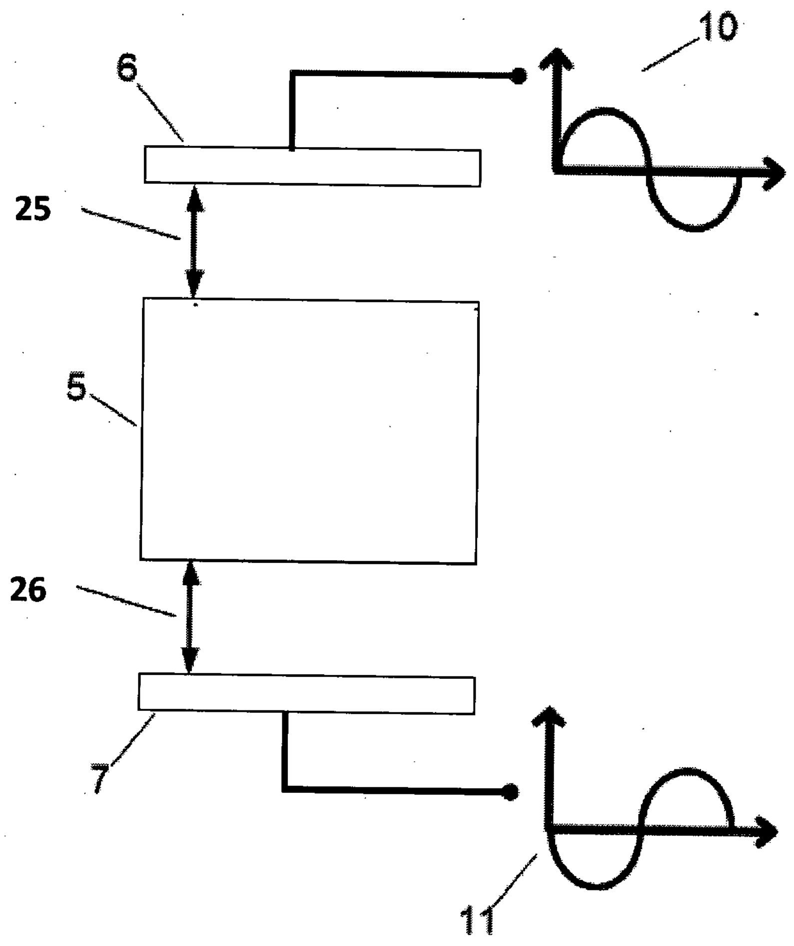

FIG. 4A

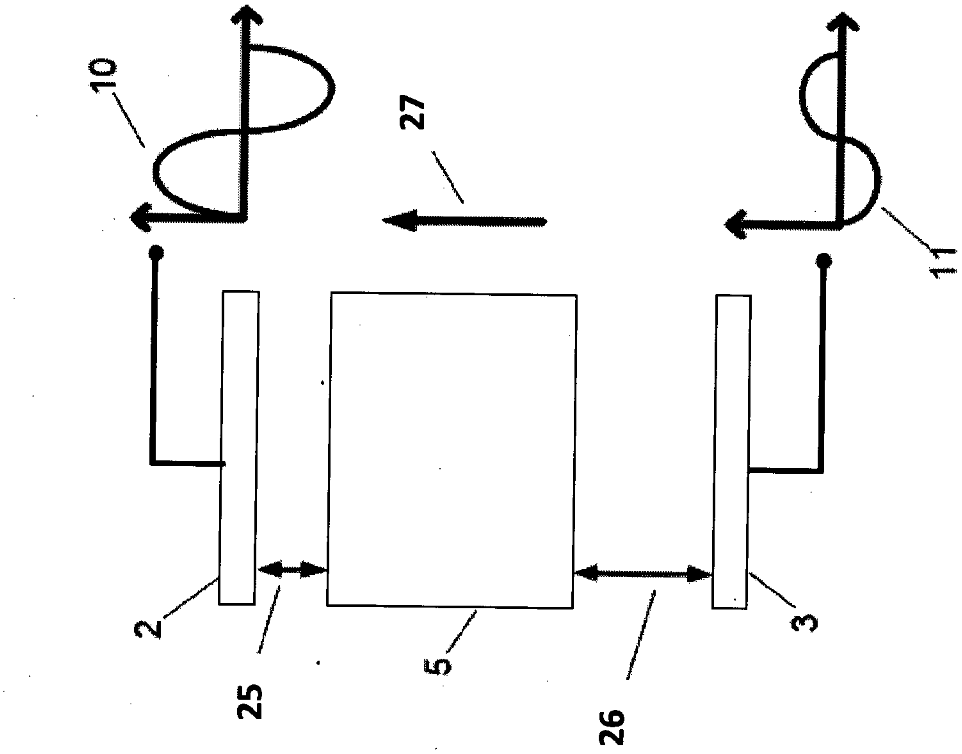

FIG. 4B

INTERNATIONAL SEARCH REPORT

International application No
PCT/TR2014/000545

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01C19/5726 G01C19/5776
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	AZGIN K ET AL: "A Novel In-Operation High g-Survivable MEMS Gyroscope", SENSORS, 2007 IEEE, IEEE, PI, 28 October 2007 (2007-10-28), pages 111-114, XP031221008, ISBN: 978-1-4244-1261-7 figures 1,3, 4(a) abstract page 111 - page 113 -----	1-10
A	WO 02/01231 A1 (MICROSENSORS INC [US]) 3 January 2002 (2002-01-03) figure 1 page 11, line 25 - page 12, line 1 page 12, lines 8-27 ----- -/--	1

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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"&" document member of the same patent family

Date of the actual completion of the international search 14 August 2015	Date of mailing of the international search report 24/08/2015
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Faivre, Olivier

INTERNATIONAL SEARCH REPORT

International application No
PCT/TR2014/000545

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2012/216612 A1 (SEEGER JOSEPH [US] ET AL) 30 August 2012 (2012-08-30) figure 8 paragraphs [0024], [0036] - [0037] -----	1
A	US 2001/037682 A1 (KONAKA YOSHIHIRO [JP] ET AL) 8 November 2001 (2001-11-08) figures 1,2 paragraphs [0022] - [0026], [0053] - [0061] -----	1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/TR2014/000545

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
WO 0201231	A1	03-01-2002	NONE			
US 2012216612	A1	30-08-2012	US	2010064805	A1	18-03-2010
			US	2012216612	A1	30-08-2012
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			DE	60112167	T2	24-05-2006
			EP	1152216	A2	07-11-2001
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			JP	2001317946	A	16-11-2001
			US	2001037682	A1	08-11-2001