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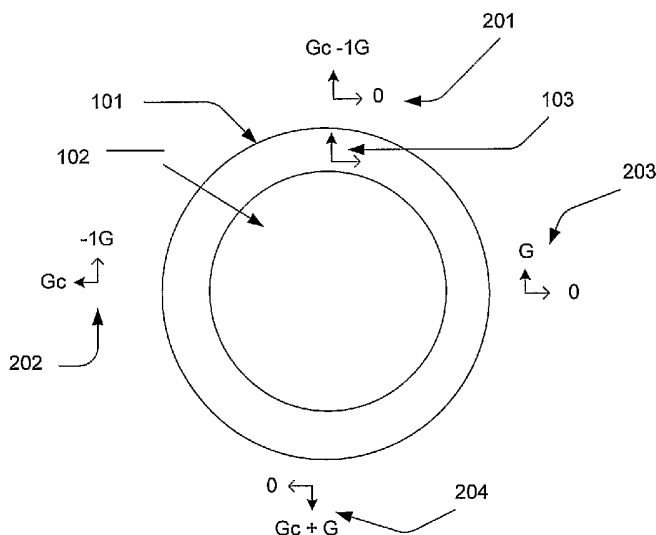
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(54) Title: TYPE PRESSURE MONITORING SYSTEM



(57) Abstract: A TPMS device 106 comprises a pair of accelerometers (103) fitted to a tyre (101) such that one accelerometer (103) measures a tangential component of acceleration as the tyre (101) rotates and the other accelerometer (103) measures a radial component of acceleration as the tyre (101) rotates. As the orientation of the two accelerometers (103) relative to gravitational acceleration varies when the tyre (101) rotates, the measured components of tangential and radial acceleration will vary as the tyre (101) rotates. By considering the relative phase between the maxima and minima measured by each accelerometer (103) it is possible to determine the direction of rotation of the tyre (101). Additionally, by considering the time separation between successive maxima it is possible to determine the rotation rate of the tyre (101). Integration of the determined rotation rate over time can determine the distance traveled by each tyre (101). Furthermore, by considering the direction of rotation it is possible to determine whether the wheel (102) to which the tyre (101) (and hence the TPMS 106) is mounted is provided on the left or right of the vehicle and to determine whether or not the wheel (102) is a steered wheel.

Tyre Pressure Monitoring System

The present invention relates to tyre pressure monitoring systems and in particular to tyre pressure monitoring systems adapted to reduce power consumption and/or to enable wheel identification during operation.

5 Tyre pressure monitoring sensors (TPMS) typically comprise a pressure sensing element provided within a tyre, the element being linked to on-vehicle control and monitoring systems by a wireless link. Power for operating such systems is typically provided by a battery. As a result, the lifetime of such systems is limited by the lifetime of the battery. A typical vehicle may be parked for around 95% of its
10 operational life. Therefore for 95% of its operating lifetime, the battery may be being drained unnecessarily. It is therefore common to provide an accelerometer within the tyre, the accelerometer operable to determine whether the tyre is or is not in motion and thus to switch the TPMS between a low power sleep mode and a normal operation mode as appropriate.

15 If each tyre on a vehicle is fitted with a TPMS, there is a need to identify which TPMS is fitted to which tyre. This can be achieved by storing the identification code of each TPMS in the on-vehicle monitoring and control system. This has the disadvantage that when a tyre is replaced, the stored code also has to be updated. As an alternative some TPMS systems are designed such that the on-vehicle monitoring
20 and control unit can identify which tyre each TPMS is fitted to by the output of each TPMS.

In US 6,446,502 and US 6,633,229 this is achieved by providing an accelerometer in each TPMS. The output of the accelerometer is analyzed to determine the tangential and centrifugal acceleration of each tyre. The differences in the magnitude of the tangential and centrifugal accelerations between the various TPMS devices are compared and then be used to determine which side of a vehicle a TPMS device is located. These systems however have the disadvantage that a difference in tangential acceleration is only detectable during acceleration or deceleration of the vehicle. Furthermore, the difference being small, to detect such a difference requires high accuracy sample and hold techniques and as such is difficult and expensive to implement with a suitably accurate low power accelerometer.

Typically, the accelerometer will be a silicon micro electronic machine (Si MEMS) device or a mechanical switch. Si MEMS accelerometers are typically require expensive integration and have low sensitivity or alternatively require expensive high power consuming electronics. Mechanical switches are prone to failure, typically when used in the harsh environment of a tyre. They can also be relatively expensive. As an alternative, it is possible to use Coriolis force sensors based on gyroscopic principles, but these would typically be too expensive for use in a TPMS.

An alternative form of motion sensor is a piezo electric sensor. These sensors generate an electrical signal in response to movement or vibration. The signal generated is not however proportional to the acceleration of the sensor and thus these sensors are not considered suitable for use as accelerometers in TPMS devices as it is

very expensive to derive an accurate quantitative value for an acceleration from the output signal. These devices are however commonly used as 'shock' sensors for CD or DVD reader/writers or for magnetic hard drives.

It is therefore an object of the present invention to provide a new TPMS and/or
5 a new method of operating a TPMS that overcomes or alleviates some or all of the above problems.

According to a first aspect of the present invention there is provided a TPMS device comprising: pressure sensing means; data transmitting means for transmitting data relating to the output of the pressure sensing means to remote devices; and a pair
10 of accelerometers, the accelerometers each operable to detect the occurrence of maxima and minima in differently directed components of acceleration.

Such a device can be used to determine the direction of rotation of a wheel and/or the distance traveled by each wheel and thus enables the identification of the vehicle wheel to which the TPMS device is fitted to be carried out.

15 If the TPMS device is fitted to a tyre, as the tyre rotates, the orientation of the TPMS device changes and accordingly, the orientation of the TPMS device relative to gravitational acceleration also varies. The accelerometers in the TPMS device thus detect variable acceleration in the differently directed components of acceleration as the tyre rotates. Constant rotation of the tyre results in the accelerometers detecting a
20 series of in minima and maxima in each component direction. The relative phase between the maxima is determined by the angle between the detected components of

acceleration. By monitoring the relative phases of the signals detected by the accelerometers, the direction of rotation of the tyre can be determined. This therefore enables a distinction to be made between tyres on the right side and tyres on the left side of a vehicle. As it is only the position or timing of a maxima (or minima) in
5 measured components of acceleration that is important and not the absolute magnitude of the acceleration, this determination can be achieved using less accurate accelerometers than are used in conventional TPMS devices. Accordingly, slower and/or less accurate processing electronics may also be used to achieve this determination than is typically the case with known TPMS devices. This results in a
10 relatively low cost TPMS device.

The accelerometers may be operable to detect acceleration in directions with any suitable mutual angle. The accelerometers are preferably operable to detect acceleration in substantially orthogonal directions. Most preferably, the TPMS device is mounted on a tyre and one accelerometer is orientated to detect radial acceleration
15 and the other is orientated to detect tangential acceleration.

The TPMS device is preferably provided with a control means. The control means may be operable to determine the time separation between the occurrences of successive maxima in one or both components of acceleration and may additionally be operable to determine the time separation between the occurrence of a maximum in
20 one component of acceleration and the occurrence of a maximum in the other component of acceleration. The control means may also be operable to determine the direction of rotation of the tyre comparing the time separations between the

occurrence of successive maxima in one component of acceleration and the time separation between the occurrence of a maximum in one component of acceleration and the occurrence of a maximum in the other component of acceleration.

The control means may be operable to determine the rotation rate of the tyre
5 by determining the time separation between successive maxima in one component of acceleration. The control means may further be operable to determine the distance traveled by the tyre by integrating the determined rotation rate of the tyre over time. By comparing the distance traveled by tyres on the same side of a vehicle, the steered tyre on one side of the vehicle can be distinguished from the non-steered tyre as
10 steered tyres will travel a longer distance. This enables such a TPMS device to determine during operation which TPMS device is fitted to which tyre of a vehicle.

Preferably, the TPMS device comprises power storage means. Most preferably, the power storage means is a battery.

Preferably, the TPMS device is operable in a normal mode or a low power
15 sleep mode and the device is switched from the sleep mode to the normal mode in response to detection of acceleration by either accelerometer and is switched from normal mode to sleep mode in the absence of the detection of acceleration from either accelerometer. Preferably, the device switches into sleep mode if there is no acceleration detected by either accelerometer detected in a predetermined time period.
20 This thus provides a simple and effective way to determine whether the tyre is in

motion as there is no acceleration if the tyre is stationary and thus the device may be switched to sleep mode to save power.

The accelerometer may be any suitable type of accelerometer including Si MEMS devices, mechanical devices and gyroscopic devices but is preferably a piezo-electric sensor. Such piezo-electric sensors have a rapid response and are relatively low cost. In the present invention it is not a concern that the output of the piezo-electric sensors is non-linear.

The TPMS device may incorporate additional sensors if desired, including but not limited to any one of or more of the following: accelerometers, vibration sensors, shock sensors, velocity sensors and temperature sensors. In such embodiments, the data transmission means are preferably operable to transmit data relating to the output of the additional sensor or sensors in addition to data relating to the output of the pressure sensor.

The data transmission means is preferably operable to transmit RF signals. The TPMS device may additionally be provided with a data receiving means operable to receive RF signals. The control means may be operable to control the operation of the data transmission means in response to the output of the pressure sensor and/or the output of one or more other sensors provided on the device and/or the output of the data receiving means.

Preferably, each data transmission comprises a unique identification code in addition to the sensor data. Preferably said identification code is stored in the control

means. The monitoring of the output of each accelerometer can be carried out by the control means or may alternatively be carried out by an on-vehicle control unit.

According to a second aspect of the present invention there is provided a method of determining the direction of rotation of a tyre using a TPMS device
5 according to the first aspect of the present invention comprising the steps of: measuring the components of acceleration in two different directions relative to the TPMS device as the tyre rotates; determining the phase difference between the occurrence of maxima and minima in the components acceleration measured in each direction; and thereby determining the direction of rotation of the tyre.

10 Determining the phase difference between the occurrence of maxima and minima in each component signal may involve determining the time separation between successive maxima in one component of acceleration and determining the time separation between the occurrence of a maximum in one component of acceleration and the occurrence of a maximum in the other component of acceleration
15 and comparing the determined time separations.

The method may further involve determining the rotation rate of the tyre by determining the time separation between successive maxima in one or both components of acceleration. The method may involve the further step of integrating the determined rotation rates for the tyre over time to determine the distance traveled
20 by the tyre.

According to a third aspect of the present invention there is provided a method of determining to which tyre of a vehicle a TPMS device according to the first aspect of the present invention is fitted, a TPMS device according to the first aspect of the present invention being fitted to each tyre of the vehicle, the method comprising the
5 steps of: determining the direction of rotation of each tyre; determining the distance traveled by each tyre; and comparing the direction of rotation and distance traveled information for each tyre to determine which side of the vehicle each tyre is fitted to, and whether or not each tyre is a steered tyre.

The third aspect of the present invention may incorporate any or all features
10 of the first and second aspects of the present invention as desired or as appropriate. In particular, the method of the third aspect of the present invention may calculate the direction of rotation of a tyre in accordance with the method of the second aspect of the present invention and may calculate the distance traveled by a tyre in accordance with the method described as an extension of the second aspect of the present
15 invention.

According to a fourth aspect of the present invention there is provided a tyre pressure monitoring system for a vehicle comprising: a TPMS device according to the first aspect of the present invention fitted to each tyre of the vehicle; an RF signal receiver; and a control unit connected to the RF signal receiver.

20 The fourth aspect of the present invention may incorporate any or all features of the first, second and third aspects of the present invention as desired or as

appropriate. In particular, the system of the fourth aspect of the present invention may operate in accordance with the method of the third aspect of the present invention.

The control unit of the system aspect of the invention may be an on-vehicle
5 control unit. In such embodiments, the method may be wholly carried out by the on-vehicle control unit or may be split between an on-vehicle control unit and the control means provided in each TPMS device.

In order that the invention is more clearly understood specific embodiments will be described further herein, with reference to the accompanying drawings in
10 which:

Figure 1 is a schematic block diagram of a TPMS device according to the present invention;

Figure 2 is a schematic diagram of a the components of acceleration detectable by an accelerometer in a TPMS device according to
15 the present invention; and

Figure 3 is a schematic diagram of the variation of the magnitude of the components of acceleration detected by an accelerometer as a wheel rotates.

Referring now to figure 3, a tyre pressure monitoring sensor (TPMS) device
20 106, comprises a pair of accelerometers 103, typically piezo-electric accelerometers, a

control means 107, a RF transmitter 108, a power source 109, typically a battery and a pressure sensor 110. The accelerometers 103, control means 107, RF transmitter 108, battery 109 and pressure sensor 110 are typically provided in a single protective housing. The accelerometers 103 are orientated at approximately 90 degrees to one
5 another such that when fitted to a tyre the device may be orientated such that one accelerometer detects radial acceleration of the tyre and the other accelerometer detects tangential acceleration of the tyre. The piezo-electric accelerometers may typically be devices similar to the MSI ACH01 or MSI ACH04 series available from MURATA.

10 In use, the control means 107 monitors the output of the pressure sensor 110 and causes the RF transmitter 108 to periodically transmit data signals indicative of the output of the pressure sensor 110. The data signals transmitted also include a unique code identifying the TPMS device. The unique code is stored by the control means 107. The provision of a unique code enables an on-vehicle control unit which
15 receives signals from TPMS devices 106 on each tyre of the vehicle to determine which transmissions originate from which TPMS device 106.

To determine which tyre of a vehicle each TPMS device 106 is fitted to, the output of the accelerometers is analysed. Referring now to figure 1, a single accelerometer 103 is shown fitted to tyre 101 of wheel 102. When the wheel is in
20 motion, the accelerometer 103 will experience at all times a radial acceleration 104 and a tangential acceleration 105. Each component will vary as the tyre 101 makes a complete rotation. Turning now to figure 2, the variation of the components of

acceleration 104, 105 for a wheel 102 revolving at a constant rate is shown. It can be seen clearly from figure 4, the components 104, 105 each include a sinusoidal component due to gravitational acceleration. For mutually perpendicular directions of measurement such a radial and tangential, the effect of the gravitational component is 90 degrees out of phase between the two components 104, 105. As a result, the maxima and minima of the acceleration components detected by each accelerometer 103 are 90 degrees out of phase.

By analysing the phase difference between the peaks in each component of acceleration, the direction of motion of the wheel can be determined. This can be carried out either by the control means 107 or the on-vehicle control unit. Typically, this may be carried out by determining the time separation between successive maxima in one component of acceleration and determining the time separation between the occurrence of a maximum in one component of acceleration and the occurrence of a maximum in the other component of acceleration and comparing the determined time separations. If the direction of rotation of each wheel 102 can be determined, then the side of the vehicle that the wheel 102 is fitted to can also be determined.

It is also possible by analysing the time separation between successive peaks in each acceleration component 104, 105 to determine the rotation rate of each wheel 102. The determined rotation rate of each wheel 102 can be integrated over time to determine the distance traveled by each wheel 102. This calculation can be carried out either by the control means 107 or the on-vehicle control unit. As the distance

traveled by the front (steering) wheel on each side of the vehicle, when turning, is greater than the distance traveled by the rear (non-steering) wheel on the same side of a vehicle this can indicate whether or not a wheel is a steered wheel.

Accordingly, a combination of the distance traveled by each wheel and the
5 direction of motion of each wheel can be used to identify which wheel on a vehicle each TPMS device 106 is fitted to.

Data transmissions from the device 106 may include data indicative of the outputs of either or both accelerometers 103 or calculated directions of motion or travel distance for each wheel as desired or as appropriate.

10 The TPMS device 106 may also be adapted to operate in two modes, a normal mode and a low power sleep mode. The device 106 is switched from sleep mode to normal mode once a change in acceleration is detected by either accelerometer 103. The device is switched from normal mode to sleep mode when no change in signal is detected by either accelerometer 103 for greater than a predetermined time period.
15 This enable the lifetime of battery 109 to be extended, and hence the useful operational lifetime of the device 106 to be extended.

It is of course to be understood that the invention is not to be restricted to the details of the above embodiments which are described by way of example only. For instance, in alternative embodiments, additional sensing means may be provided
20 and/or an RF signal receiver may be provided.

Claims

1. A TPMS device comprising: pressure sensing means; data transmitting means
for transmitting data relating to the output of the pressure sensing means to
remote devices; and a pair of accelerometers, the accelerometers each operable
5 to detect the occurrence of maxima and minima in differently directed
components of acceleration.
2. A TPMS device as claimed in claim 1 wherein the accelerometers are operable
to detect acceleration in mutually orthogonal directions.
3. A TPMS device as claimed in claim 2 wherein the TPMS device is mounted
10 on a tyre such that one accelerometer is operable to detect radial acceleration
of the tyre and the other accelerometer is operable to detect tangential
acceleration of the tyre.
4. A TPMS device as claimed in any preceding claim wherein the TPMS device
is provided with a control means.
- 15 5. A TPMS device as claimed in claim 4 wherein the control means is operable
to determine the time separation between the occurrences of successive
maxima in one or both components of acceleration.
6. A TPMS device as claimed in claim 4 or claim 5 wherein the control means is
operable to determine the time separation between the occurrence of a
20 maximum in one component of acceleration and the occurrence of a maximum
in the other component of acceleration.

7. A TPMS device as claimed in claim 6 when dependent upon claim 3 wherein the control means is operable to determine the direction of rotation of the tyre comparing the time separations between the occurrence of successive maxima in one component of acceleration and the time separation between the occurrence of a maximum in one component of acceleration and the occurrence of a maximum in the other component of acceleration.
8. A TPMS device as claimed in any one of claims 5 to 7, when dependent upon claim 3 wherein the control means is operable to determine the rotation rate of the tyre by determining the time separation between successive maxima in one component of acceleration.
9. A TPMS device as claimed in claim 8 wherein the control means is operable to determine the distance traveled by the tyre by integrating the determined rotation rate of the tyre over time.
10. A TPMS device as claimed in any preceding claim wherein the TPMS device comprises power storage means.
11. A TPMS device as claimed in claim 10 wherein the power storage means is a battery.
12. A TPMS device as claimed in any preceding claim wherein the TPMS device is operable in a normal mode or a low power sleep mode.
13. A TPMS device as claimed in claim 12 wherein the TPMS device is switched from the sleep mode to the normal mode in response to detection of acceleration by either accelerometer and is switched from normal mode to

sleep mode if there is no acceleration detected by either accelerometer detected in a predetermined time period.

14. A TPMS device as claimed in any preceding claim wherein one or both accelerometers are Si MEMS devices, mechanical devices or gyroscopic devices.

15. A TPMS device as claimed in any preceding claim wherein one or both accelerometers are piezo-electric sensors.

16. A TPMS device as claimed in any preceding claim wherein the TPMS device incorporates any one of or more of the following additional sensors: accelerometers, vibration sensors, shock sensors, velocity sensors and temperature sensors.

17. A TPMS device as claimed in claim 16 wherein the data transmission means are operable to transmit data relating to the output of the additional sensor or sensors in addition to data relating to the output of the pressure sensor.

18. A TPMS device as claimed in any preceding claim wherein the data transmission means is operable to transmit RF signals.

19. A TPMS device as claimed in any preceding claim wherein the TPMS device is provided with a data receiving means operable to receive RF signals.

20. A TPMS device as claimed in claim 19 wherein the control means is operable to control the operation of the data transmission means in response to the output of the pressure sensor and/or the output of the accelerometers and/or the output of the one or more additional sensors provided on the device and/or the output of the data receiving means.

21. A TPMS device as claimed in any preceding claim wherein each data transmission comprises a unique identification code in addition to the sensor data.
22. A TPMS device as claimed in any one of claims 4 to 21 wherein said
5 identification code is stored in the control means.
23. A method of determining the direction of rotation of a tyre using a TPMS device according to the first aspect of the present invention comprising the steps of: measuring the components of acceleration in two different directions relative to the TPMS device as the tyre rotates; determining the phase
10 difference between the occurrence of maxima and minima in the components acceleration measured in each direction; and thereby determining the direction of rotation of the tyre.
24. A method as claimed in claim 23 wherein determining the phase difference between the occurrence of maxima and minima in each component signal
15 involves determining the time separation between successive maxima in one component of acceleration and determining the time separation between the occurrence of a maximum in one component of acceleration and the occurrence of a maximum in the other component of acceleration and comparing the determined time separations.
- 20 25. A method as claimed in claim 23 or claim 24 wherein the method further involves determining the rotation rate of the tyre by determining the time separation between successive maxima in one or both components of acceleration.

26. A method as claimed in claim 25 wherein the method involves the further step of integrating the determined rotation rates for the tyre over time to determine the distance traveled by the tyre.
27. A method of determining to which tyre of a vehicle a TPMS device according to any one of claims 1 to 22 is fitted, such a TPMS device being fitted to each tyre of the vehicle, the method comprising the steps of: determining the direction of rotation of each tyre; determining the distance traveled by each tyre; and comparing the direction of rotation and distance traveled information for each tyre to determine which side of the vehicle each tyre is fitted to, and whether or not each tyre is a steered tyre.
28. A method as claimed in claim 27 wherein the direction of rotation of the tyre is calculated by the method of claims 23 or 24.
29. A method as claimed in any one of claims 27 or 28 wherein the distance traveled by the tyre is calculated by the method of claim 26.
30. A tyre pressure monitoring system for a vehicle comprising: a TPMS device according to any one of claims 1 to 22 fitted to each tyre of the vehicle; an RF signal receiver; and a control unit connected to the RF signal receiver.
31. A tyre pressure monitoring system as claimed in claim 30 wherein the system operates in accordance with the method of claims 27 to 29
32. A tyre pressure monitoring system as claimed in claim 30 or claim 31 wherein the control unit of the system is an on-vehicle control unit.
33. A tyre pressure monitoring system as claimed in claim 32 wherein the calculation of tyre rotation direction, tyre rotation rate, tyre distance traveled

and which TPMS device is fitted to which tyre is wholly carried out by the on-vehicle control unit.

34. A tyre pressure monitoring system as claimed in claim 32 wherein the calculation of tyre rotation direction, tyre rotation rate, tyre distance traveled
- 5 and which TPMS device is fitted to which tyre is split between an on-vehicle control unit and the control means provided in each TPMS device.

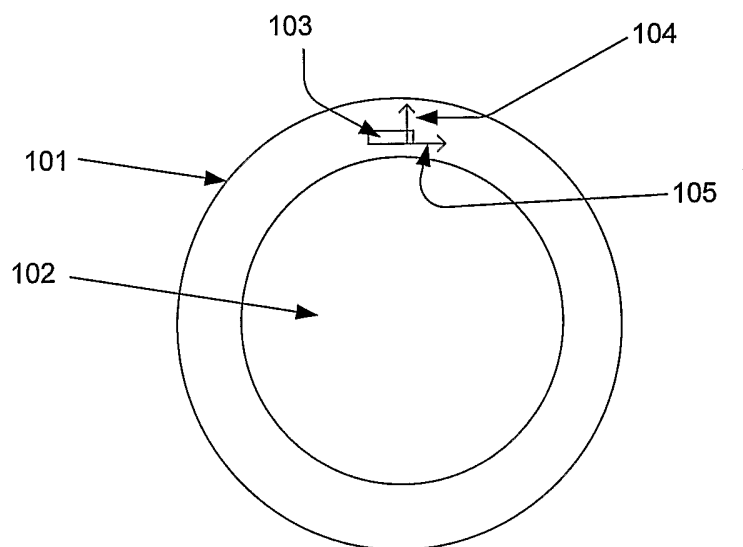


Figure 1

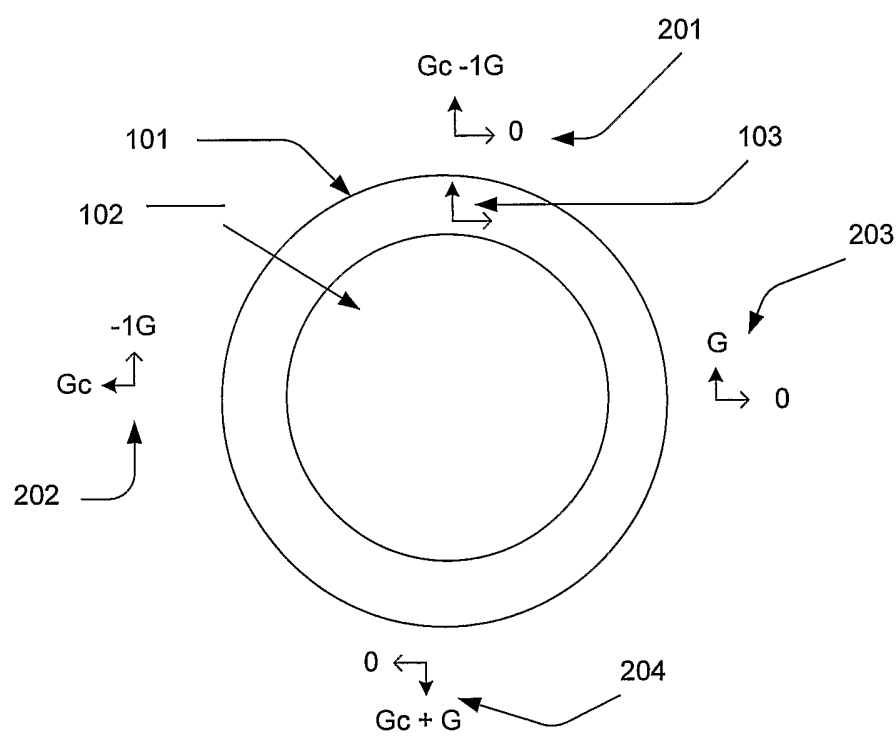


Figure 2

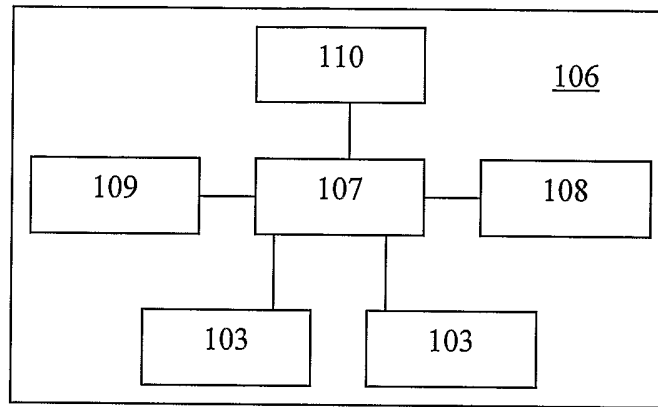


Figure 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2006/000662

A. CLASSIFICATION OF SUBJECT MATTER

INV. B60C23/04

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)
B60C

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 practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2003/197603 A1 (STEWART WILLIAM DAVID ET AL) 23 October 2003 (2003-10-23) paragraph [0104] - paragraph [0154] figures 1,7-19 -----	1-34

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

☒ See patent family annex.

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Date of the actual completion of the international search

8 June 2006

Date of mailing of the international search report

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Authorized officer

Billen, K

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2006/000662

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2003197603 A1	23-10-2003	AU 2003228539 A1 EP 1494877 A1 WO 03089260 A1	03-11-2003 12-01-2005 30-10-2003