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13/077,127 31 March 2011 (31.03.2011) US(71) Applicant (for all designated States except US): **AL-LEGRO MICROSYSTEMS, INC.** [US/US]; 115 North-east Cutoff, Worcester, MA 01606 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **FRIEDRICH, Andreas, P.** [DE/FR]; 51 route des Grands Pres, F-74370 Metz-Tessy (FR). **FOLETTTO, Andrea** [IT/FR]; 1 rue des Pavillons, F-74000 Annecy (FR). **VIG, Ravi** [US/US]; 6 Longview Drive, Bow, NH 03304 (US).(74) Agents: **CROWLEY, Judith, C.** et al.; Daly, Crowley, Mofford & Durkee, LLP, Suite 301A, 354A Turnpike Street, Canton, MA 02021 (US).

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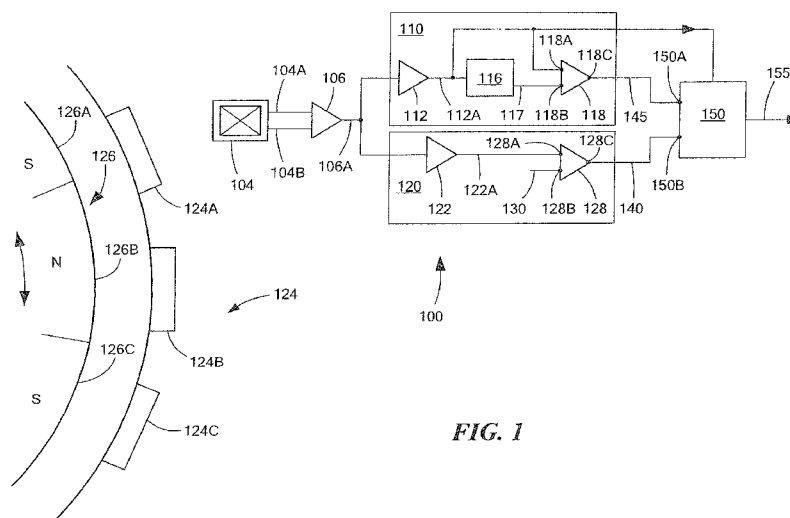
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**FIG. 1**

(57) **Abstract:** A circuit detects object movement using one or more predetermined threshold detectors (100) based on a predetermined threshold of a magnetic field signal associated with a magnetic field of an object (124) and also using one or more tracking threshold detectors by tracking the magnetic field signal over time. The circuit includes an output selector (150) to generate an output related to the output of one of the predetermined threshold detectors (120) or the tracking threshold detectors (110) based on a predetermined condition. In some embodiments, the predetermined condition is related to a number of cycles of a magnetic field signal or the calibration time period of the tracking threshold detectors. A method associated with the circuit is also described.

CIRCUITS AND METHODS FOR MOTION DETECTION

FIELD OF THE INVENTION

[0001] This invention relates generally to integrated circuits and, more particularly, to
5 integrated circuits for detecting a movement of a ferromagnetic object.

BACKGROUND

[0002] Magnetic field sensors (e.g., rotation detectors) for detecting ferromagnetic articles
and/or magnetic articles are known. The magnetic field associated with the ferromagnetic
10 article or magnetic article is detected by a magnetic field sensing element, such as a Hall
element or a magnetoresistance element, which provides a signal (i.e., a magnetic field
signal) proportional to a detected magnetic field. In some arrangements, the magnetic field
signal is an electrical signal.

15 [0003] The magnetic field sensor processes the magnetic field signal to generate an output
signal that changes state each time the magnetic field signal crosses thresholds, either near
to peaks (positive and/or negative peaks) or near to some other level, for example, zero
crossings of the magnetic field signal. Therefore, the output signal has an edge rate or
period indicative of a movement speed (e.g., a rotation speed) of the ferromagnetic or
20 magnetic object, for example, a gear or a ring magnet.

[0004] One application for a magnetic field sensor is to detect the approach and retreat of
each tooth of a rotating ferromagnetic gear, either a hard magnetic gear or a soft
ferromagnetic gear. In some particular arrangements, a ring magnet having magnetic
25 regions (including permanent or hard magnetic material) with alternating polarity is coupled
to the ferromagnetic gear or is used by itself. The magnetic field sensor is responsive to
approach and retreat of the magnetic regions of the ring magnet. In other arrangements, a
gear is disposed proximate to a stationary magnet and the magnetic field sensor is
responsive to perturbations of a magnetic field as the gear rotates.

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[0005] In one type of magnetic field sensor, sometimes referred to as a peak-to-peak
percentage detector (or threshold detector), one or more threshold levels are equal to
respective percentages of the peak-to-peak magnetic field signal. One such peak-to-peak

percentage detector is described in U.S. Patent No. 5,917,320 entitled "Detection of Passing Magnetic Articles While Periodically Adapting Detection Threshold" and assigned to the assignee of the present invention.

5 [0006] Another type of magnetic field sensor, sometimes referred to as a slope-activated detector (or peak referenced detector), is described in U.S. Patent No. 6,091,239 entitled "Detection Of Passing Magnetic Articles With a Peak Referenced Threshold Detector," also assigned to the assignee of the present invention. In the peak referenced magnetic field sensor, the threshold signal differs from the positive and negative peaks (i.e., the peaks and
10 valleys) of the magnetic field signal by a predetermined amount. Thus, in this type of magnetic field sensor, the output signal changes state when the magnetic field signal comes away from a peak or valley of the magnetic field signal by the predetermined amount.

[0007] It should be understood that, because the above-described threshold detector and the
15 above-described peak referenced detector both have circuitry that can identify the positive and negative peaks of a magnetic field signal, the threshold detector and the peak referenced detector both include a circuit portion, which is configured to detect positive peaks and/or negative peaks of the magnetic field signal. The threshold detector and the peak referenced detector, however, each use the detected peaks in different ways.

20 [0008] In order to accurately detect the positive and negative peaks of a magnetic field signal, the rotation detector is capable of tracking at least part of the magnetic field signal. To this end, typically, one or more digital-to-analog converters (DACs) can be used to generate a tracking signal, which tracks the magnetic field signal. For example, in the
25 above-referenced U.S. Patent Nos. 5,917,320 and 6,091,239, two DACs are used, one (PDAC) to detect the positive peaks of the magnetic field signal and the other (NDAC) to detect the negative peaks of the magnetic field signal.

[0009] Some types of rotation detectors perform one or more types of initialization or
30 calibration, for example, at a time near to start up or power up of the rotation detector, or otherwise, from time to time as desired. During one type of calibration, the above-described threshold level is determined. In some types of calibration, a time interval during which the calibration occurs is determined in accordance with a predetermined number of cycles of the

magnetic field signal. Thus, for fast magnetic field signals (e.g., for fast rotating gears), the time available for calibration is small. In those applications for which the movement or rotation is rapid and the time available for calibration is small, the rotation detector might not provide accurate motion detection fast enough.

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[0010] It would, therefore, be desirable to provide a movement detector (e.g., a rotation detector) that can provide accurate and reliable motion detection (rotation speed and/or rotation direction) within a relatively short time frame, as well as over relatively long time frames.

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SUMMARY

[0011] In general overview, the invention is directed to aspects of a circuit capable of detecting movement of an object within a relatively short period of time and, in some embodiments, detecting a speed and/or a direction of movement of an object within a relatively short period of time. The circuit detects object movement using one or more predetermined threshold detectors based on a predetermined threshold of a magnetic field signal associated with a magnetic field of an object. The circuit also detects object movement using one or more tracking threshold detectors by tracking the magnetic field signal over time. The predetermined threshold detectors can detect object movement quickly in comparison to the tracking threshold detectors, which require a calibration period (for example, a period which may include a period from startup or power up of a circuit) to track positive and negative peaks of the magnetic field signal. The circuit includes an output selector to generate an output related to the output of one of the predetermined threshold detectors or the tracking threshold detectors based on a predetermined condition. In some embodiments, the predetermined condition is related to a number of cycles of a magnetic field signal or the calibration time period of the tracking threshold detectors.

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[0012] In some embodiments, a circuit capable of detecting a speed and a direction of a moving object includes a pair of predetermined threshold detectors responsive to a first pair of magnetic field elements (operative to provide a first magnetic field signal) and a second pair of magnetic field elements (operative to provide a second magnetic field signal). The first and second magnetic field signals are proportional to responses of the first and second pairs of magnetic field elements. The circuit also includes a pair of tracking threshold

detectors responsive to the first and second magnetic field signals. The output selector generates an output signal related to a combination of output signals generated by the pair of predetermined threshold detectors and the pair of tracking threshold detectors based on the predetermined condition.

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[0013] The circuit may be used in applications in which it is desired, needed, or necessary to detect object movement quickly and to generate an output signal indicative of such object movement. The object is not limited to any particular type of object which may include, but is not limited to, a toothed gear, crankshaft, camshaft, mechanical component of a toy or tool, etc. The object may include a ferromagnetic object, such as a soft ferromagnetic object. By way of non-limiting examples, the circuit may be used to detect movement of gears in a vehicle (for example, direction of rotation of transmission gears during vehicle operation), movement of vehicle wheels (for example, to generate an output signal indicative of forward or backward movement of a vehicle), etc.

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[0014] In accordance with one aspect of the invention, a circuit responsive to movement of an object includes a magnetic field sensing element operative to provide a magnetic field signal proportional to a magnetic field associated with the object, a predetermined threshold detector including a comparator having a first input responsive to the magnetic field signal, a second input responsive to a predetermined threshold, and an output at which is provided a predetermined threshold detector output signal, and a tracking threshold detector including a tracking circuit coupled to receive the magnetic field signal and configured to track positive and negative peaks of the magnetic field signal and to generate a tracking signal, and a comparator having a first input responsive to the magnetic field signal, a second input responsive to an input signal related to the tracking signal, and an output at which is provided a tracking threshold detector output signal. The circuit also includes an output signal selector having a first input responsive to the tracking threshold detector output signal, a second input responsive to the predetermined threshold detector output signal, and configured to generate a circuit output signal related to at least one of the predetermined threshold detector output signal or the tracking threshold detector output signal based upon a predetermined condition.

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[0015] In further embodiments, the circuit includes one or more of the following features:

the predetermined condition is related to a predetermined number of cycles of the magnetic field signal; the predetermined condition is related to a predetermined number of cycles of the predetermined threshold detector output signal; the predetermined condition corresponds to a predetermined time; at least one of an automatic gain control coupled to the magnetic field sensing element and configured to process the magnetic field signal, wherein the predetermined condition corresponds to a condition of the automatic gain control, or an automatic offset adjustment coupled to the magnetic field sensing element and configured to process the magnetic field signal, wherein the predetermined condition corresponds to a condition of the automatic offset adjustment, and; the output signal selector is further configured to generate the circuit output signal related to the predetermined threshold detector output signal during a calibration time period of the tracking threshold detector and to generate the circuit output signal related to the tracking threshold detector output signal after the calibration time period wherein the predetermined condition corresponds to the end of the calibration time period.

[0016] In another embodiment, the circuit includes one or more of the following features: the magnetic field sensing element is a first pair of magnetic field sensing elements, the magnetic field signal is a first magnetic field signal, and the predetermined threshold detector is a first predetermined threshold detector responsive to the first magnetic field signal and operative to provide a first predetermined threshold detector output signal having a first predetermined threshold detector phase, the circuit further including a second pair of magnetic field sensing elements operative to provide a second magnetic field signal, and a second predetermined threshold detector including a comparator having a first input responsive to the second magnetic field signal, a second input responsive to the predetermined threshold, and an output at which is provided a second predetermined threshold detector output signal having a second predetermined threshold detector phase, wherein the signal selector further includes a third input responsive to the second predetermined threshold detector output signal and a difference between the first and second predetermined threshold detector phases is indicative of a movement direction of the object; the predetermined condition is related to a predetermined number of cycles of one of the first or second magnetic field signals; the predetermined condition is related to a predetermined number of cycles of one of the first or second predetermined threshold detector output signals; the predetermined condition corresponds to a predetermined time,

and; at least one of an automatic gain control coupled to one of the first pair or the second pair of magnetic field sensing elements and configured to process a corresponding one of the first or second magnetic field signals, wherein the predetermined condition corresponds to a condition of the automatic gain control, or an automatic offset adjustment coupled to one of the first pair or the second pair of magnetic field sensing elements and configured to process a corresponding one of the first or second magnetic field signals, wherein the predetermined condition corresponds to a condition of the automatic gain control.

[0017] In a further embodiment, the circuit includes one or more of the following features:

the magnetic field sensing element is a first pair of magnetic field sensing elements and the magnetic field signal is a first magnetic field signal, and the tracking threshold detector is a first tracking threshold detector responsive to the first magnetic field signal and operative to provide a first tracking threshold detector output signal having a frequency indicative of movement speed of the object and a first tracking threshold detector phase, the circuit further including a second pair of magnetic field sensing elements operative to provide a second magnetic field signal, and a second tracking threshold detector including a tracking circuit coupled to receive the second magnetic field signal and configured to track positive and negative peaks of the second magnetic field signal and to generate a second tracking signal and a comparator having a first input responsive to the second magnetic field signal, a second input responsive to an input signal related to the second tracking signal, and an output at which is provided a second tracking threshold detector output signal having a second tracking threshold detector phase wherein the signal selector further includes a third input responsive to the second tracking threshold detector output signal and a difference between the first and second tracking threshold detector phases is indicative of a movement direction of the object; the predetermined condition is related to a predetermined number of cycles of one of the first or second magnetic field signals; the predetermined condition is related to a predetermined number of cycles of one of the first or second tracking threshold detector output signals; the predetermined condition corresponds to a predetermined time; at least one of an automatic gain control coupled to one of the first pair or the second pair of magnetic field sensing elements and configured to process a corresponding one of the first or second magnetic field signals, wherein the predetermined condition corresponds to a condition of the automatic gain control, or an automatic offset adjustment coupled to one of the first pair or the second pair of magnetic field sensing elements and configured to process

a corresponding one of the first or second magnetic field signals, wherein the predetermined condition corresponds to a condition of the automatic offset adjustment; the predetermined threshold detector is a first predetermined threshold detector responsive to the first magnetic field signal and the first predetermined threshold detector comparator is responsive to a first predetermined threshold and is operative to provide a first predetermined threshold detector output signal having a frequency indicative of movement speed of the object and a first predetermined threshold detector phase, the circuit further including a second predetermined threshold detector including a second comparator circuit having an input responsive to the second magnetic field signal and another input responsive to a second predetermined threshold and operative to provide a second predetermined threshold detector output signal having a second predetermined threshold detector phase wherein the signal selector further comprises a fourth input responsive to the second predetermined threshold detector output signal and a difference between the first and second predetermined threshold detector phases is indicative of a movement direction of the object; at least one of the first or second predetermined threshold detectors includes a Schmitt trigger; the output signal selector further includes a third input responsive to the second tracking threshold detector output signal and a fourth input responsive to the second predetermined threshold detector output signal and is further configured to provide the circuit output signal corresponding to a combination of the first and second tracking threshold detector output signals or a combination of the first and second predetermined threshold detector output signals based upon the predetermined condition; the predetermined condition is related to a predetermined number of cycles of one of the first or second magnetic field signals; the predetermined condition is related to a predetermined number of cycles of one of the first predetermined threshold detector output signal, second predetermined threshold detector output signal, first tracking threshold detector output signal, or second tracking threshold detector output signal; the predetermined condition corresponds to a predetermined time, and; at least one of an automatic gain control coupled to one of the first pair or the second pair of magnetic field sensing elements and configured to process a corresponding one of the first or second magnetic field signals, wherein the predetermined condition corresponds to a condition of the automatic gain control, or an automatic offset adjustment coupled to one of the first pair or the second pair of magnetic field sensing elements and configured to process a corresponding one of the first or second magnetic field signals, wherein the predetermined condition corresponds to a condition of the automatic offset adjustment.

[0018] In accordance with another aspect of the invention, a circuit responsive to movement of an object includes a first pair of magnetic field sensing elements operative to provide a first magnetic field signal proportional to a magnetic field associated with the object, a second pair of magnetic field sensing elements operative to provide a second magnetic field signal proportional to the magnetic field, a first predetermined threshold detector including a first comparator circuit having an input responsive to the first magnetic field signal and another input responsive to a first predetermined threshold and an output at which is provided a first predetermined threshold detector output signal having a frequency indicative of movement speed of the object and a first predetermined threshold detector phase, a second predetermined threshold detector including a second comparator circuit having an input responsive to the second magnetic field signal and another input responsive to a second predetermined threshold and an output at which is provided a second predetermined threshold detector output signal having a second predetermined threshold detector phase, wherein a difference between the first and second predetermined threshold detector phases is indicative of a movement direction of the object, a first tracking threshold detector responsive to the first magnetic field signal and an output at which is provided a first tracking threshold detector output signal having a frequency indicative of a tracking threshold speed of the object and a first tracking threshold detector phase, a second tracking threshold detector responsive to the second magnetic field signal and an output at which is provided a second tracking threshold detector output signal having a second tracking threshold detector phase different than the first tracking threshold detector phase, wherein a difference between the first and second tracking threshold detector phases is indicative of the movement direction of the object. The circuit also includes an output signal selector coupled to receive the first predetermined threshold detector output signal, the second predetermined threshold detector output signal, the first tracking threshold detector output signal, and the second tracking threshold detector output signal and configured to generate a circuit output signal related to at least one of the received detector signals based upon a predetermined condition.

[0019] In a further embodiment, the circuit includes one or more of the following features: the predetermined condition is related to a predetermined number of cycles of one of the first or second magnetic field signals; the predetermined condition is related to a

predetermined number of cycles of one of the first predetermined threshold detector output signal, second predetermined threshold detector output signal, first tracking threshold detector output signal, or second tracking threshold detector output signal; the

predetermined condition corresponds to a predetermined time, and; at least one of an

5 automatic gain control coupled to one of the first pair or the second pair of magnetic field sensing elements and configured to process a corresponding one of the first or second

magnetic field signals, wherein the predetermined condition corresponds to a condition of the automatic gain control, or an automatic offset adjustment coupled to one of the first pair or the second pair of magnetic field sensing elements and configured to process a

10 corresponding one of the first or second magnetic field signals, wherein the predetermined condition corresponds to a condition of the automatic offset adjustment.

[0020] In accordance with yet another aspect, a method of detecting a movement of an object includes generating a magnetic field signal proportional to a magnetic field

15 associated with the object, generating a tracking signal responsive to the magnetic field signal to track positive and negative peaks of the magnetic field signal, generating a

predetermined threshold output signal responsive to the magnetic field signal and to a predetermined threshold, generating a tracking threshold output signal responsive to the

magnetic field signal and to the tracking signal, and providing an overall output signal

20 related to a selected one of the predetermined threshold output signal or the tracking threshold output signal based upon a predetermined condition.

[0021] In another embodiment, the method includes one or more of the following features:

the predetermined condition is related to a predetermined number of cycles of the magnetic

25 field signal; the predetermined condition is related to a predetermined number of cycles of

the predetermined threshold output signal; the predetermined condition corresponds to a

predetermined time; processing the magnetic field signal using at least one of an automatic

gain control, wherein the predetermined condition corresponds to a condition of the

automatic gain control, or an automatic adjustment control, wherein the predetermined

30 condition corresponds to a condition of the automatic adjustment control; said providing the

overall output signal further includes selecting the overall output signal to be related to the

predetermined threshold output signal during a calibration time period, and selecting the

overall output signal to be related to the tracking threshold output signal after the calibration

time period, wherein the predetermined condition corresponds to the end of the calibration time period; said magnetic field signal is a first magnetic field signal proportional to a magnetic field of the object at a first position, said tracking signal is a first tracking signal responsive to the first magnetic field signal, said tracking threshold output signal is a first tracking threshold output signal responsive to the first magnetic field signal and to the first tracking signal, wherein the first tracking threshold output signal has a frequency indicative of a movement speed of the object and a first tracking threshold output signal phase, and said predetermined threshold output signal is a first predetermined threshold output signal responsive to the first magnetic field signal and to a first predetermined threshold, the first predetermined threshold output signal having a frequency indicative of the movement speed of the object and having a first predetermined threshold output signal phase, further including generating a second magnetic field signal proportional to a second magnetic field associated with the object at a second position offset from the first position, generating a second tracking signal responsive to the second magnetic field signal to track positive and negative peaks of the second magnetic field signal, generating a second tracking threshold output signal responsive to the second magnetic field signal and to the second tracking signal and having a second tracking threshold output signal phase, a difference of the first and second tracking threshold output signal phases indicative of a movement direction of the object, and generating a second predetermined threshold output signal responsive to the second magnetic field signal and to a second predetermined threshold and having a second predetermined threshold output signal phase, a difference of the first and second output signal phases indicative of movement direction of the object, wherein said overall output signal is further related to a selected one of a combination of the first and second predetermined threshold output signals or a combination of the first and second tracking threshold output signals based upon the predetermined condition; the predetermined condition is related to a predetermined number of cycles of one of the first or second magnetic field signals; the predetermined condition is related to a predetermined number of cycles of one of the first predetermined threshold detector output signal, second predetermined threshold detector output signal, first tracking threshold detector output signal, or second tracking threshold detector output signal; the predetermined condition corresponds to a predetermined time, and; further including processing one of the first or second magnetic field signals using at least one of an automatic gain control, wherein the predetermined condition corresponds to a condition of the automatic gain control, or an

automatic offset adjustment, wherein the predetermined condition corresponds to a condition of the automatic offset adjustment.

BRIEF DESCRIPTION OF THE DRAWINGS

5 [0022] The foregoing features of the invention, as well as the invention itself may be more fully understood from the following detailed description of the drawings, in which:

[0023] FIG. 1 is a block diagram showing an exemplary circuit for object motion detection, having a predetermined threshold detector, a tracking threshold detector, and an output
10 signal selector;

[0024] FIG. 2 is a block diagram showing another exemplary circuit for object motion detection, having one or more predetermined threshold detectors, one or more tracking threshold detectors, and an output signal selector;
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[0025] FIG. 3 is a block diagram showing an exemplary peak-to-peak percentage detector that can be used in the tracking threshold detector of FIG. 1;

[0026] FIG. 4A is a block diagram showing an exemplary peak referenced detector that can
20 be used in the tracking threshold detector of FIG. 1;

[0027] FIG. 4B is a graph showing illustrative waveforms associated with the peak referenced detector of FIG. 4A;

25 [0028] FIG. 5 is a block diagram showing an exemplary zero-crossing detector that can be used in the tracking threshold detector of FIG. 1;

[0029] FIG. 6 is a flow chart representative of a method for object motion detection that may be implemented in the circuit of FIGS. 1 and 2;
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[0030] FIG. 7 is a graph showing magnetic field signals and predetermined threshold detector output signals associated with a circuit embodiment of FIG. 2;

[0031] FIG. 8 is a graph showing magnetic field signals and tracking threshold detector output signals associated with a circuit embodiment of FIG. 2; and

5 [0032] FIG. 9 is a graph showing output signal selection of an output signal selector that can be used with a circuit embodiment of FIG. 2.

DETAILED DESCRIPTION

[0033] Before describing the inventive systems, methods, and techniques, some introductory concepts and terminology are explained. As used herein, the term "magnetic
10 field sensing element" is used to describe a variety of types of electronic elements that can sense a magnetic field. The magnetic field sensing elements can be, but are not limited to, Hall effect elements, magnetoresistance elements, or magnetotransistors. As is known, there are different types of Hall effect elements. These Hall effect elements may be made of a IV type semiconductor material such as Silicon (Si) or Germanium (Ge), or a III-V type
15 semiconductor material such as Gallium-Arsenide (GaAs) or an Indium compound, for example, Indium-Antimonide (InSb).

[0034] As is also known, there are different types of magnetoresistance elements, for example, anisotropic magnetoresistance (AMR) elements, giant magnetoresistance (GMR)
elements, tunneling magnetoresistance (TMR) elements, and magnetic tunnel junction
20 (MTJ) elements.

[0035] Some of the above-described magnetic field sensing elements tend to have an axis of maximum sensitivity parallel to a substrate that supports the magnetic field sensing element, and others of the above-described magnetic field sensing elements tend to have an axis of
25 maximum sensitivity perpendicular to a substrate that supports the magnetic field sensing element. In particular, most, but not all, types of magnetoresistance elements tend to have axes of maximum sensitivity parallel to the substrate and most, but not all, types of Hall elements tend to have axes of sensitivity perpendicular to a substrate.

30 [0036] As used herein, the term "magnetic field sensor" is used to describe a circuit that includes a magnetic field sensing element. Magnetic field sensors are used in a variety of applications including, but not limited to, a current sensor that senses a magnetic field generated by a current carried by a current-carrying conductor, a magnetic switch or

proximity detector that senses the proximity of a ferromagnetic or magnetic object, a motion detector (e.g., a rotation detector) that senses passing ferromagnetic articles, for example, magnetic domains of a ring magnet or teeth of a ferromagnetic gear, and a magnetic field sensor that senses a magnetic field density of a magnetic field. Rotation detectors are used as examples herein. However, the circuits and techniques described herein apply also to any magnetic field sensor capable of detecting a motion of an object.

[0037] Operation of a magnetic field sensor in a so-called “calibration mode,” also referred to herein as an “initialization mode,” is described herein. Reference is also made herein to operation of a magnetic field sensor in a so-called “running mode.” The calibration mode can occur at the beginning of operation (or from time to time as desired) and the running mode is achieved at other times. Operation of the running mode is described in greater detail in one or more of the above-mentioned patents, notably, U.S. Patent No. 5,917,320 and U.S. Patent No. 7,362,094, which are incorporated by reference herein in their entirety.

[0038] While a calibration time period is discussed herein, and end of which ends the calibration mode discussed herein in accordance with certain criteria, it should be recognized that other calibrations can be performed after the end of the indicated calibration time period. For example, an automatic gain control can continue calibrating after the end of the indicated calibration time period. At some point after the end of the indicated calibration time period, but not necessarily coincident with the end of the indicated calibration time period, the magnetic field sensors described herein can enter the running mode, during which updates to values of circuit parameters can update in a different way than during the calibration mode.

[0039] Referring to FIG. 1, an exemplary circuit 100 responsive to movement of an object 124 includes a magnetic field sensing element 104 for generating differential signal 104A, 104B (i.e., a magnetic field signal) proportional to a magnetic field associated with the object 124. The magnetic field sensing element 104 can include, but is not limited to, a Hall effect element, a magnetoresistance element, or a magnetotransistor.

[0040] The object 124 can be an object configured to rotate, for example, a ferromagnetic gear. The circuit 100 can include an amplifier 106 coupled to receive the differential signal

104A, 104B from the magnetic field sensing element 104 and configured to generate a signal 106A (also a magnetic field signal).

[0041] Circuit 100 also includes a predetermined threshold detector 120. In some
5 embodiments, the predetermined threshold detector 120 includes an amplifier 122 coupled to receive the signal 106A and configured to generate a signal 122A (also a magnetic field signal). In some embodiments, the amplifier 122 includes an automatic gain control (AGC) amplifier and/or the circuit 100 includes an automatic offset adjustment (AOA).

10 [0042] The predetermined threshold detector 120 can include a comparator 128 having a first input 128A responsive to the magnetic field signal 122A, a second input 128B responsive to a predetermined threshold 130, and an output 128C at which is provided a predetermined threshold detector output signal 140. In some embodiments, the
15 predetermined threshold 130 is an electrical signal having a reference voltage value, for example 1.5 volts.

[0043] Circuit 100 also includes a tracking threshold detector 110. In some embodiments, the tracking threshold detector 110 includes an amplifier 112 coupled to receive the signal
20 106A and configured to generate a signal 112A (also a magnetic field signal). In some embodiments, the amplifier 112 includes an AGC amplifier and/or the circuit 100 includes an AOA.

[0044] The tracking threshold detector 110 can include a tracking circuit 116 coupled to receive the signal 112A and configured to track positive and negative peaks of the signal
25 112A and to generate a tracking signal 117. The tracking threshold detector 110 can also include comparator 118 having a first input 118A responsive to signal 112A, a second input 118B responsive to an input signal related to the tracking signal 117, and an output 118C at which is provided a tracking threshold detector output signal 145.

30 [0045] In further embodiments discussed in detail herein below, the tracking threshold detector 110 includes a peak-to-peak percentage detector (FIG. 3), a peak referenced detector (FIGS. 4A and 4B), a zero-crossing detector (FIG. 5), or combinations thereof.

[0046] In some embodiments, detectors 110, 120 are rotation detectors to detect rotational movements of the object 124, while in some other embodiments, detectors 110, 120 are translation detectors to detect translational movements of the object 124. It should be noted that detectors 110, 120 are not limited to detection of stated kinds of object movement, and may detect other types of object movements, including combinations of object rotation and translation.

[0047] It should be noted that signals 104A, 104B, 106A, 112A, 122A are all magnetic field signals, and are all indicative of a magnetic field experienced by the magnetic field sensing element 104.

[0048] Circuit 100 can also include an output signal selector 150 having a first input 150A responsive to the tracking threshold detector output signal 145, a second input 150B responsive to the predetermined threshold detector output signal 140, and configured to generate a circuit output signal 155 related to at least one of the predetermined threshold detector output signal 140 or the tracking threshold detector output signal 145 based upon a predetermined condition.

[0049] As will be described more fully below in conjunction with FIGS. 8 and 9, in some embodiments, output signal selector 150 is configured to generate the circuit output signal 155 related to the predetermined threshold detector output signal 140 during a calibration time period of the tracking threshold detector 110 and to generate the circuit output signal 155 related to the tracking threshold detector output signal 145 after the calibration time period wherein the predetermined condition corresponds to the end of the calibration time period.

[0050] In some embodiments, the predetermined condition is related to a predetermined number of cycles of the magnetic field signal 106A, for example, three cycles.

[0051] In other embodiments, the predetermined condition is related to a predetermined number of cycles of the predetermined threshold detector output signal 140, for example, three cycles.

[0052] In still other embodiments, the predetermined condition corresponds to a predetermined time, for example, 1.0 second. In some embodiments, the predetermined time is related to the rotation speed and/or a predetermined time after rotation is detected. For faster rotation speeds, the time can be shorter while for slower rotation speeds the time can be longer.

[0053] In other embodiments, the circuit 100 includes at least one of an AGC or an AOA coupled to the magnetic field sensing element 104 and configured to process the signal (as may be similar to signal 106A). In these embodiments, the predetermined condition corresponds to a condition of the AGC, for example, a gain of the AGC that has not changed for 3 cycles of the signal or a condition of the AOA, for example, an offset value of the AOA.

[0054] The predetermined condition should not be construed as limited to the above described conditions but can also be based on various algorithms to determine when tracking threshold detector 110 is calibrated and to determine proper rotation speed and/or direction information.

[0055] In some arrangements, the magnetic field sensing element 104 can be responsive to motion of the object 124, for example, motion of ferromagnetic gear teeth upon a gear, of which gear teeth 124A-124C upon the gear 124 are representative. To this end, a fixed magnet (not shown) can be disposed proximate to the magnetic field sensing element 104 and the gear teeth can disturb the magnetic field generated by the magnet as the gear rotates. However, in other arrangements, the magnetic field sensing element 104 can be responsive to movement of magnetic regions upon a magnet, for example, magnetic regions 126A-126C upon a ring magnet 126. In some particular arrangements, the ring magnet 126 and the gear 124 are coupled together with a shaft or the like. In these particular arrangements, the ring magnet 126 can be proximate to the magnetic field sensing element 104.

[0056] The magnetic field sensing element 104 is responsive to proximity of the ring magnet 126 and, in particular, to proximity of passing magnetic regions north (N) and south (S) 126A-126C. In operation, the magnetic field sensing element 104 produces the differential magnetic field signal 104A, 104B (and also the magnetic field signals 106A,

112A, 122A) having a generally repeating pattern when the ring magnet 126 rotates, wherein each peak (positive and negative) of the pattern is associated with one of the magnetic regions N, S.

5 [0057] Referring now to FIG. 2, in a further embodiment, a circuit 200 includes a first predetermined threshold detector 220A, a second predetermined threshold detector 220B, and a tracking threshold detector 210A. The circuit 200 can also include a first pair of magnetic field sensing elements 205A, including magnetic field sensing element 204A and magnetic field sensing element 204C, operative to provide a differential magnetic field
10 signal 274A, 274B, 294A, 294B proportional to a magnetic field associated with an object 224. In some embodiments, the circuit 200 can include an amplifier 206A coupled to receive a differential signal 274A, 274B from the first pair of magnetic field sensing elements 205A and configured to generate a signal 276A (also a magnetic field signal).

15 [0058] In some embodiments, the first predetermined threshold detector 220A can include an amplifier 222A coupled to receive the signal 276A and configured to generate a signal 272B (also a magnetic field signal). In some embodiments, the amplifier 222A includes an AGC amplifier and/or the circuit 100 includes an AOA.

20 [0059] The first predetermined threshold detector 220A can include a comparator 228A having a first input 278A responsive to the magnetic field signal 272B, a second input 278B responsive to a predetermined threshold 230A, and an output 278C at which is provided a first predetermined threshold detector output signal 240A. The predetermined threshold 230A may include a plurality of predetermined thresholds, for example, a first
25 predetermined threshold and a second predetermined threshold.

[0060] The circuit 200 can also include a second pair of magnetic field sensing elements 205B, including magnetic field sensing element 204B and magnetic field sensing element 204C, operative to provide a second differential magnetic field signal 284A, 284B, 294A, 294B proportional to the magnetic field associated with object 224. In some embodiments,
30 circuit 200 can include an amplifier 206B coupled to receive the differential signal 284A, 284B, 294A, 294B from the second pair of magnetic field sensing elements 205B and configured to generate a signal 286A (also a magnetic field signal).

[0061] In further embodiments, the second predetermined threshold detector 220B includes an amplifier 222B coupled to receive the signal 286A and configured to generate a signal 282B (also a magnetic field signal). In still further embodiments, the amplifier 222B includes an AGC amplifier and/or the circuit 100 includes an AOA.

[0062] The second predetermined threshold detector 220B can also include a comparator 228B having a first input 288A responsive to the magnetic field signal 282B, a second input 288B responsive to a predetermined threshold 230B, and an output 288C at which is provided a second predetermined threshold detector output signal 240B. In some embodiments, the predetermined threshold 230B of detector 220B is the same as the predetermined threshold 230A of detector 220A, while in some other embodiments, the predetermined thresholds 230A, 230B are different.

[0063] In some embodiments, the tracking threshold detector 210A of circuit 200 includes an amplifier 212A coupled to receive the signal 276A and configured to generate a signal 272A (also a magnetic field signal). In some embodiments, the amplifier 212A includes an AGC amplifier and/or the circuit 100 includes an AOA.

[0064] The tracking threshold detector 210A can include a tracking circuit 216A coupled to receive the signal 272A and configured to track positive and negative peaks of the signal 272A and to generate a tracking signal 277A. The tracking threshold detector 210A can also include a comparator 218A having a first input 278A responsive to signal 272A, a second input 278B responsive to an input signal related to the tracking signal 277A, and an output 278C at which is provided a first tracking threshold detector output signal 245A.

[0065] The circuit 200 can also include an output signal selector 250 (as may be similar to output signal selector 150 described in conjunction with FIG. 1) having a first input 250A responsive to the tracking threshold detector output signal 245A, a second input 250B responsive to the first predetermined threshold detector output signal 240A, and a third input 250C responsive to the second predetermined threshold detector output signal 240B. The output signal selector 250 is configured to generate a circuit output signal 255 related to at least one of the first predetermined threshold detector output signal 240A, the tracking

threshold detector output signal 245A, or the second predetermined threshold detector output signal 240B based upon a predetermined condition.

[0066] Output signal selector 250 selects signals 245A, 245B, 240A, 240B based on a predetermined condition and includes logic for example to determine speed and/or direction and/or vibration information based on one or more of these signals. For example, higher signal edge rates can correspond to relatively fast object movement and lower signal edge rates can correspond to relatively slow object movement. In embodiments in which the object is a rotating gear, for example, signal frequency (related to edge rate) is indicative of rotation speed of the gear. The relative phase sequences of rising and falling edges of two of the signals can be used to determine a direction of object movement. It will be understood that logic to determine speed and/or direction information may include analog logic, digital logic, and/or mixed logic.

[0067] In these embodiments, the first predetermined threshold detector output signal 240A has a first predetermined threshold detector phase and the second predetermined threshold detector output signal 240B has a second predetermined threshold detector phase. A difference between the first and second predetermined threshold detector phases is indicative of a movement direction of the object 224. A frequency of either the predetermined threshold detector output signal 240A, the threshold detector output signal 245A, or the second predetermined threshold detector output signal 240B is related to a speed of rotation of the object 224.

[0068] In a further embodiment, the predetermined condition is related to a predetermined number of cycles of one of the first or second magnetic field signals 276A, 286A, for example, three cycles.

[0069] In another embodiment, the predetermined condition is related to a predetermined number of cycles of one of the first or second predetermined threshold detector output signals 240A, 240B, for example, three cycles.

[0070] In a further embodiment, the predetermined condition corresponds to a predetermined time. In some embodiments, the predetermined time is related to the rotation

speed and/or a predetermined time after rotation is detected.

[0071] In another embodiment, circuit 200 includes an AGC coupled to one of the first or second pair of magnetic field sensing elements 205A, 205B and configured to process a
5 respective one of the first or second magnetic field signals (276A, 286A) wherein the predetermined condition corresponds to a condition of the AGC, for example, a gain of the AGC. Circuit 200 optionally includes an AOA coupled to one of the first or second pair of magnetic field sensing elements 205A, 205B and configured to process a respective one of the first or second magnetic field signals (276A, 286A) wherein the predetermined
10 condition corresponds to a condition of AOA.

[0072] Referring again to FIG. 2, in another embodiment, the circuit 200 includes the first tracking threshold detector 210A, a second tracking threshold detector 210B, and the first predetermined threshold detector 220A. In this embodiment, circuit 200 includes the first
15 pair of magnetic field sensing elements 205A and the second pair of magnetic field sensing elements 205B.

[0073] In some embodiments, the second tracking threshold detector 210B includes an amplifier 212B coupled to receive the signal 286A (from the second magnetic field sensing
20 element 205B) and configured to generate a signal 282A (also a magnetic field signal). In some embodiments, the amplifier 212B is an AGC amplifier and/or the circuit 100 includes an AOA.

[0074] The second tracking threshold detector 210B can include a tracking circuit 216B
25 coupled to receive the signal 282A and configured to track positive and negative peaks of the signal 282A and to generate a tracking signal 277B. The second tracking threshold detector 210B can also include a comparator 218B having a first input 288A responsive to signal 282A, a second input 288B responsive to an input signal related to the tracking signal 277B, and an output 288C at which is provided a second tracking threshold detector output
30 signal 245B.

[0075] In this embodiment, the circuit 200 includes the output signal selector 250 (as may be similar to output signal selector 150 described in conjunction with FIG. 1) having a first

input 250A responsive to the first tracking threshold detector output signal 245A, a second input 250D responsive to the second tracking threshold detector output signal 245B, and a third input 250B responsive to the first predetermined threshold detector output signal 240A. The output signal selector 250 is configured to generate a circuit output signal 255 related to at least one of the first tracking threshold detector output signal 245A, the first predetermined threshold detector output signal 240A, or the second tracking threshold detector output signal 245B based upon a predetermined condition.

[0076] In this embodiment, the first tracking threshold detector output signal 245A has a first tracking threshold detector phase and the second tracking threshold detector output signal 245B has a second tracking threshold detector phase. A difference between the first and second tracking threshold detector phases is indicative of a movement direction of the object 224. A frequency of either the first tracking threshold detector output signal 245A, the first predetermined threshold detector output signal 240A, or the second tracking threshold detector output signal 245B is related to a speed of rotation of the object 224.

[0077] Referring yet again to FIG. 2, in a further embodiment, a circuit 200 includes the first tracking threshold detector 210A, the second tracking threshold detector 210B, the first predetermined threshold detector 220A, and the second predetermined threshold detector 220B. In this embodiment, the output signal selector 250 includes a first input 250A responsive to the first tracking threshold detector output signal 245A, a second input 250B responsive to the first predetermined threshold detector output signal 240A, a third input 250C responsive to the second predetermined threshold detector output signal 240B, and a fourth input 250D responsive to the second tracking threshold detector output signal 245B. In such an arrangement, the output signal selector 250 is configured to provide the circuit output signal 255 corresponding to a combination of the first and second tracking threshold detector output signals 245A, 245B or a combination of the first and second predetermined threshold detector output signals 240A, 240B based upon the predetermined condition.

[0078] In a further embodiment, the predetermined condition is related to a predetermined number of cycles of one of the first or second magnetic field signals 276A, 286A, for example, three cycles.

[0079] In a further embodiment, the predetermined condition is related to a predetermined number of cycles of one of the first predetermined threshold detector output signal 240A, the second predetermined threshold detector output signal 240B, the first tracking threshold detector output signal 245A, or the second tracking threshold detector output signal 245B, for example, three cycles.

[0080] In a further embodiment, at least one of the first or second predetermined threshold detectors 220A, 220B includes a Schmitt trigger.

[0081] It should be apparent to one of ordinary skill in the art that the circuit is not limited to above-described configurations, and may encompass other desired configurations including multiple tracking threshold detectors (i.e., more than two tracking threshold detectors) and/or multiple predetermined threshold detectors (i.e., more than two predetermined threshold detectors).

[0082] Operation of the circuits 100, 200 is described below in conjunction with FIG. 7 – 9.

[0083] Referring now to FIG. 3, a peak-to-peak percentage detector 26 suitable for use as the tracking circuit 116 of FIG. 1 is shown. Peak-to-peak percentage detector 26 is coupled to a comparator 428, like comparator 118 of FIG. 1. A magnetic field signal 18, like signal 112A of FIG. 1, is provided as an input to the detector 26.

[0084] Magnetic field signal 18 is applied to a non-inverting input of a first comparator 400 and to the inverting input of a second comparator 404. The output signals of comparators 400 and 404 provide input signals GT_PDAC 458 and LT_NDAC 461, respectively, to an update controller 409 that provides control signals to counters 414 and 430, as shown.

[0085] The update controller 409 provides a p_updn signal 463 to an UPDN (up/down) input of a counter 414 to control the count direction. As will become apparent, the p_updn signal 463 normally causes the counter 414 to count up. Under certain conditions however, the p_updn signal 463 causes the counter 414 to count down for some clock cycles. The counter 414 is clocked by a system clock signal, CLK. A p_hold signal 465 is coupled to a HOLD input of the counter 414. The counter output is held constant (i.e., the counter is

disabled) when the HOLD input signal is at a first logic level and is released (i.e., the counter is enabled) when HOLD input signal is at a second logic level. The counter 414 may be a six bit counter which is enabled when the HOLD input is low.

- 5 [0086] The outputs of the counter 414 are coupled to inputs of a positive digital-to-analog converter (PDAC) 403. The PDAC 403 is buffered by a buffer 424 to provide a PDAC signal 402, which may be a voltage that tracks positive peaks of the magnetic field signal 18 (i.e., a tracking signal).
- 10 [0087] The comparator 400, counter 414, PDAC 403, and buffer 424 comprise a “positive portion” of the detector circuitry. A “negative portion” of the detector 26 is similarly arranged, as shown. In particular, update controller 409 provides an n_updn signal 466 to an UPDN input of counter 430 to control the count direction. As will become apparent, the n_updn signal 466 normally causes the counter 430 to count down. Under certain
- 15 conditions however, the n_updn signal 466 causes the counter 430 to count up for some clock cycles. The counter 430 is clocked by a system clock signal, CLK. An n_hold signal 468 is coupled to a HOLD input of the counter 430. The counter output is held constant (i.e., the counter is disabled) when the HOLD input signal is at a first logic level and is released (i.e., the counter is enabled) when the HOLD input signal is at a second logic level.
- 20 The counter 430 may be a six bit counter which is enabled when the HOLD input is low.

- [0088] The outputs of the counter 430 are coupled to inputs of a negative digital-to-analog converter (NDAC) 405. The NDAC 405 is buffered by a buffer 436 to provide an NDAC signal 406, which may be a voltage that tracks negative peaks of the magnetic field signal
- 25 18 (i.e., a tracking signal).

- [0089] The buffered PDAC and NDAC signals 402, 406 are coupled to a resistor divider comprising series-coupled resistors 408, 412, and 416 in order to generate peak-to-peak threshold signals THRESHHI and THRESHLO, as will be described more fully below in
- 30 conjunction with FIG. 8.

[0090] Each of the threshold signals THRESHHI and THRESHLO is a percentage of the difference between the PDAC and NDAC voltages, or, in other words, a percentage of the

peak-to-peak magnetic field signal 18. As described more fully below in conjunction with FIG. 8, in one embodiment, an upper threshold value 440 is at approximately 75% of the peak-to-peak signal and a lower threshold value 444 is at approximately 25% of the peak-to-peak signal. It will be appreciated that other percentages may be suitable. Switches 424a and 424b are arranged and controlled so as to apply one of the threshold levels to comparator 428, as shown. Switch 424b is controlled by the POSCOMP signal. In particular, switch 424a is controlled by an inverted version of the POSCOMP signal, or POSCOMP_N. Further, the magnetic field signal 18 is applied to a non-inverting input of comparator 428.

[0091] Referring now to FIG. 4A, a peak referenced detector 10 suitable for use as the tracking threshold detector 110 of FIG. 1 is shown, which uses a single digital-to-analog converter (DAC) 28 to track a magnetic field signal 2. The magnetic field signal 2 is coupled to an inverting input of a tracking comparator 20 which receives at a non-inverting input an output signal PEAKDAC (i.e., the tracking signal) of a DAC 28, as shown. The magnetic field signal 2 is further coupled to an inverting input of a comparator 40, like comparator 118 of FIG. 1, which receives at the non-inverting input the PEAKDAC signal and which generates a detector output signal, POSCOMP. The comparator 40 has internal hysteresis, here on the order of 100 mV, so that the POSCOMP output signal changes state when the magnetic field signal 2 exceeds the PEAKDAC signal by approximately 100 mV. The output signal of the comparator 20, COMPOUT, is coupled to an exclusive OR (XOR) gate 36 which additionally receives the POSCOMP signal and which provides a HOLD input signal to an up/down counter 24. Counter 24 is further responsive to a clock signal, CLK, and to the POSCOMP signal for controlling whether counter 24 counts up or down. The output of the counter 24 is converted into the tracking PEAKDAC signal by the DAC 28.

[0092] As illustrated in FIG. 4B, whenever the magnetic field signal 2 exceeds the PEAKDAC signal by the small hysteresis level of comparator 20, the COMPOUT signal transitions to a logic high level. The HOLD input to the counter 24 is coupled to the exclusive OR (XOR) gate 36, which is coupled to COMPOUT and additionally receives the POSCOMP signal. Once the counter 24 counts up one step, the COMPOUT signal goes low causing the count value to be held until the signal exceeds the PEAKDAC signal by the

small hysteresis level of comparator 20 again. When the signal reaches a positive peak, as occurs at time t_1 , the PEAKDAC signal stays above the signal 2, thereby causing the HOLD input to the counter 24 to be asserted until the hysteresis of the comparator 40 has been overcome, as occurs when the POSCOMP signal goes low, just before time t_2 . In this way, the positive and negative peaks of the signal are tracked by the PEAKDAC signal and the detector output signal POSCOMP transitions when the signal differs from the PEAKDAC signal by more than the hysteresis amount of comparator 40 (as occurs at times t_0 and t_2).

[0093] Referring now to FIG. 5, a so-called “zero-crossing detector” 500, a tracking and comparator circuit, can be compared with the tracking circuit 116 and comparator 118 of FIG. 1. Here, an amplifier 506 is coupled to receive signals 502A, 502B, 504A, 504B from two magnetic field sensing elements 502, 504. The amplifier 506 is configured to generate a differential magnetic field signal 506A, 506B coupled to a band pass filter (BPF) 508. The magnetic field signal 506A, 506B is comparable to the magnetic field signal 106A of FIG. 1. The BPF 508 is configured to generate a differential filtered signal 508A, 508B. A comparator 528 is coupled to receive the differential filtered signal 508A, 508B and configured to generate a motion signal, POSCOMP 510A.

[0094] Referring now to FIG. 6, a method 600 of detecting a movement of an object includes, at 602 generating a magnetic field signal proportional to a magnetic field associated with the object, at 604, generating a tracking signal responsive to the magnetic field signal to track positive and negative peaks of the magnetic field signal, at 606, generating a predetermined threshold output signal responsive to the magnetic field signal and to a predetermined threshold, at 608, generating a tracking threshold output signal responsive to the magnetic field signal and to the tracking signal and, at 610, providing an overall output signal related to a selected one of the predetermined threshold output signal or the tracking threshold output signal based upon a predetermined condition.

[0095] It should be appreciated that method 600 could be implemented in a circuit, for example, circuit 100 described in conjunction with FIG. 1, or circuit 200 described in conjunction with FIG. 2. Furthermore, one or more of the method steps (i.e., steps 602, 604, 606, 608, 610) may be implemented in a processor and, in particular, may be implemented as computer software instructions loaded from a memory into a processor for

execution.

[0096] Alternatively, one or more of the method steps may be performed by functionally equivalent circuits such as a digital signal processor circuit or an application specific integrated circuit (ASIC). The method does not depict the syntax of any particular programming language. Rather, the method illustrates the information one of ordinary skill in the art requires to fabricate circuits or to generate computer software to perform the processing required to implement at least a portion of the techniques described herein. It will be appreciated by those of ordinary skill in the art that the particular sequence of steps described is illustrative only and can be varied without departing from the spirit of the techniques described herein.

[0097] In a further embodiment of method 600, the predetermined condition is related to a predetermined number of cycles of the magnetic field signal. In a non-limiting example, a processor may process the magnetic field signal to recognize a predetermined number of cycles of the magnetic field signal (for example, three cycles of the magnetic field signal). The processor determines that the predetermined condition has been met (i.e., that three cycles of the magnetic field signal have occurred) and provides an overall output signal by selecting one of the predetermined threshold output signal or the tracking threshold output signal. In one configuration, the processor provides an overall output signal related to the predetermined threshold output signal before the predetermined condition is realized (i.e., before the processor recognizes the predetermined number of cycles of the magnetic field signal), and provides the overall output signal related to the tracking threshold output signal after the predetermined condition is realized (i.e., after the processor recognizes the predetermined number of cycles of the magnetic field signal).

[0098] In another embodiment of the method 600, the predetermined condition is related to a predetermined number of cycles of the predetermined threshold output signal. In a non-limiting example, a processor may process the predetermined threshold output signal to recognize a predetermined number of cycles of the signal (for example, three cycles of the predetermined threshold output signal). The processor determines that the predetermined condition has been met (i.e., that three cycles of the predetermined threshold output signal have occurred) and provides an overall output signal by selecting one of the predetermined

threshold output signal or the tracking threshold output signal. In one configuration, the processor provides an overall output signal related to the predetermined threshold output signal before the predetermined condition is realized (i.e., before the processor recognizes three cycles of the predetermined threshold output signal), and provides the overall output signal related to the tracking threshold output signal after the predetermined condition is realized (i.e., after the processor recognizes the three cycles of the predetermined threshold output signal).

[0099] In a further embodiment of the method 600, the predetermined condition corresponds to a predetermined time. The predetermined time may optionally be related to a calibration time of a circuit, such as circuit 100 described in conjunction with FIG. 1 or circuit 200 described in conjunction with FIG. 2. As will be described more fully below, the calibration time may correspond to a calibration period related to offset and gain adjustments of the differential signals.

[0100] Accordingly, in a further embodiment, the method 600 includes selecting the overall output signal to be related to the predetermined threshold output signal during a calibration time period and selecting the overall output signal to be related to the tracking threshold output signal after the calibration time period. In this way, the predetermined condition corresponds to the end of the calibration time period.

[0101] In a non-limiting example, a processor provides a selected one of the predetermined threshold output signal or the tracking threshold output signal based upon the predetermined time (for example, in some embodiments, the time is related to target rotation speed). In a further embodiment, the predetermined time is defined relative to a time at which an object whose movement is to be detected begins to move or a time at which a circuit (as may be the same or similar to circuit 200) starts up or powers up. In a non-limiting example, the object is a rotating gear coupled to a rotating shaft of an engine. The rotating gear can be used to detect motion (and, more particularly, the speed and direction of motion) of engine components. By way of a non-limiting example, for a vehicle, this may include motion detection of a crankshaft, exhaust camshaft, intake camshaft, piston, connecting rods, valves, transmission gears, wheels, etc.

[0102] It should be noted that the predetermined time may be defined relative to various timing events. For example, the above-mentioned engine may be placed in a neutral state during which engine components are at rest (or at idle) and no movement detection is desired or necessary. However, once the engine is engaged and components begin to operate, the processor tracks the elapsed time and provides the predetermined threshold output signal until reaching the predetermined time, after which, the processor provides the tracking threshold output signal.

[0103] In another embodiment, the method 600 includes processing the magnetic field signal using an AGC, wherein the predetermined condition corresponds to a condition of the AGC, for example, at a time when the AGC stops updating. In still further embodiments, the method 600 includes processing the magnetic field signal using an AOA, wherein the predetermined condition corresponds to a condition of the AOA, for example, an offset value.

[0104] Referring now to FIG. 7, a graph 700 has a horizontal axis with a scale in arbitrary units of time and a vertical axis in arbitrary units of voltage. One portion 700A of the graph 700 includes a time-varying magnetic field signal 772A representative of, for example, the magnetic field signal 272B of FIG. 2. The magnetic field signal 772A is responsive to a magnetic field associated with the movement of an object, as may be similar to object 224 described in conjunction with FIG. 2.

[0105] Another portion 700C of the graph 700 includes a predetermined threshold detector output signal 740A representative of, for example, the predetermined threshold detector output signal 240A output from predetermined threshold detector 220A of FIG. 2. In operation, the predetermined threshold detector output signal 740A is representative of the output of a comparator (as may be similar to comparator 228A described in conjunction with FIG. 2) coupled at a first input to the magnetic field signal 772A and at a second input to a reference voltage representative of a predetermined threshold Th . The magnetic field signal 772A crosses the predetermined threshold Th (here point 773A, 773B) as it heads toward and away from a peak of the signal 772A (an example of such a peak is designated by reference numeral 771), causing the output of the comparator to change from a first state (an example of which is designated by reference numeral 776) to a second state (an example

of which is designated by reference numeral 774), and then back to the first state 776. The first and second states 776, 774 of the predetermined threshold detector output signal 740A are separated by positive and negative edges (examples of which are designated respectively by reference numerals 775A and 775B). In the same or different embodiment, the

5 predetermined threshold T_h includes a first predetermined threshold (i.e., predetermined threshold at point 773A) and a second predetermined threshold (for example, predetermined threshold at point 773C) which induce the first and second states 776, 774.

[0106] In some embodiments, the first and second states 776, 774 of the predetermined
10 threshold detector output signal 740A are responsive to a time-varying magnetic field associated with an object and sensed by a pair of magnetic field sensing elements (as may be similar to first pair of magnetic field sensing elements 205A described in conjunction with FIG. 2), which provides the signal 772A. The magnetic field signal 772A exhibits a pattern (which is shown here for simplicity to be a sinusoidal pattern) related to the time-
15 varying magnetic field produced by the object as it moves past the magnetic field sensing elements (and, more particularly, as portions of the object, such as gear teeth 224A, 224B, 224C of object 224, move past the magnetic field sensing elements). The first and second states 776, 774 of the predetermined threshold detector output signal 740A can be said to encode the cycles of the pattern and, in this way, are indicative of object movement that
20 induces the pattern. In some embodiments, the second state 774 is related to portions of the object (such as a subset of the gear teeth having a north or south polarity) as they move past the magnetic field sensing elements. In some embodiments, the magnetic field signal 772A saturates (examples of which are designated by reference numerals 779A and 779B).

25 [0107] Another portion 700B of the graph 700 includes a time-varying magnetic field signal 772B representative of, for example, the magnetic field signal 282B of FIG. 2. The magnetic field signal 772B is responsive to a magnetic field associated with the movement of an object, as may be similar to object 224 described in conjunction with FIG. 2.

30 [0108] Graph 700 (at portion 700C) includes a predetermined threshold detector output signal 740B representative of, for example, the predetermined threshold detector output signal 240B output from predetermined threshold detector 220B of FIG. 2. In operation, the predetermined threshold detector output signal 740B is representative of the output of a

comparator (as may be similar to comparator 228B described in conjunction with FIG. 2) coupled at a first input to the magnetic field signal 772B and at a second input to a reference voltage representative of a predetermined threshold T_h . The magnetic field signal 772B crosses the predetermined threshold T_h (here points 783A, 783B) as it heads toward and
5 away from a peak of signal 772B (an example of such a peak is designated by reference numeral 781) causing the output of the comparator to change from a first state (an example of which is designated by reference numeral 786) to a second state (an example of which is designated by reference numeral 784), and then back to the first state 776. The first and second states 786, 784 of the predetermined threshold detector output signal 740B are
10 separated by positive and negative edges (examples of which are designated respectively by reference numerals 785A and 785B).

[0109] In some embodiments, the first and second states 786, 784 of the predetermined threshold detector output signal 740B are responsive to a time-varying magnetic field
15 associated with an object and sensed by a pair of magnetic field sensing element (as may be similar to second pair of magnetic field sensing elements 205B described in conjunction with FIG. 2), which provides the signal 772B. The magnetic field signal 772B exhibits a pattern (which is shown here for simplicity to be a sinusoidal pattern) related to the time-varying magnetic field as the object moves past the magnetic field sensing elements (and,
20 more particularly, as portions of the object, such as gear teeth 224A, 224B, 224C of object 224, move past the magnetic field sensing elements). The first and second states 786, 784 of the predetermined threshold detector output signal 740B can be said to encode cycles of the pattern and, in this way, are indicative of object movement that induces the pattern. In some embodiments, the second state 784 is related to portions of the object (such as a subset
25 of the gear teeth having a north or south polarity) as they move past the magnetic field sensing elements.

[0110] An edge rate or period of the predetermined threshold detector output signals 740A, 740B are indicative of a speed of object movement. In other words, higher edge rates
30 correspond to relatively fast object movement and lower edge rates correspond to relatively slow object movement. In embodiments in which the object is a rotating gear, signal frequency is indicative of rotation speed of the gear.

[0111] In FIG. 7, an orientation of triangular icons 777 is indicative of a direction of object movement. As can be seen in graph 700, all of the icons are oriented toward the right-hand side of the paper indicating that the object is moving in the same direction over the entire graphed time. Furthermore, the predetermined threshold detector output signals 740A, 740B can be said to have a relative phase. The relative phase sequences of rising and falling edges can be used to determine a direction of object movement. In embodiments in which the object is a rotating gear, icon direction is indicative of clockwise or counter-clockwise rotational movement of the gear.

[0112] Referring now to FIG. 8, a graph 800 has a horizontal axis with a scale in arbitrary units of time and a vertical axis in arbitrary units of voltage. One portion 800A of the graph 800 includes a time-varying magnetic field signal 872A representative of, for example, the magnetic field signal 272A of FIG. 2. The magnetic field signal 872A is responsive to a magnetic field associated with the movement of an object, as may be similar to object 224 described in conjunction with FIG. 2. In normal operation, a PDAC signal 874A, which may be representative of the PDAC signal 402 described in conjunction with FIG. 3, can acquire and track positive peaks (an example of which is designated by reference numeral 871A). The PDAC signal 874A attempts to track the magnetic field signal 872A between various times in the cycle, for example, between times t_1 and t_2 , eventually achieving a positive peak of the magnetic field signal 872A at about time t_5 , which may be within about three cycles (or over a time period which may be related to a rotation speed of the detection target) of the magnetic field signal 872A. The PDAC signal 874A holds at other times.

[0113] It should be noted that the PDAC signal 874A is generated at times before achieving a positive peak of the magnetic field signal 872A (such times denoted by dashed line box 890A), but is inaccurate and does not represent the true motion detection information and so is not shown in FIG. 8. It should also be noted that in some embodiments, PDAC signal 874A is released just before positive peaks of magnetic field signal 872A (for example, just before positive peak 871A) and tracks the magnetic field signal 872A as it acquires the peak.

[0114] Similarly, an NDAC signal 876A, which may be representative of the NDAC signal 406 described in conjunction with FIG. 3, can acquire and track negative peaks (an example

of which is designated by reference numeral 881A). The NDAC signal 876A attempts to track the magnetic field signal 872A between various times in the cycle, for example, between times t_3 and t_4 , eventually achieving a negative peak of the magnetic field signal 872A at about time t_6 , which may also be within about three cycles of the magnetic field signal 872A. The NDAC signal 876A holds at other times.

[0115] It should be noted that the NDAC signal 876A is generated at times before achieving a negative peak of the magnetic field signal 872A (such times denoted by dashed line box 892A), but is inaccurate and does not represent the true motion detection information and so is not shown in FIG. 8. It should also be noted that in some embodiments, NDAC signal 876A is released just before negative peaks of magnetic field signal 872A (for example, just before negative peak 881A) and tracks the magnetic field signal 872A as it acquires the peak.

[0116] Another portion 800B of the graph 800 includes a time-varying magnetic field signal 872B representative of, for example, the magnetic field signal 282A of FIG. 2. The magnetic field signal 872B is responsive to a magnetic field associated with the movement of an object, as may be similar to object 224 described in conjunction with FIG. 2. In normal operation, a PDAC signal 874B, which may be representative of the PDAC signal 402 described in conjunction with FIG. 3, can acquire and track positive peaks (an example of which is designated by reference numeral 871B). The PDAC signal 874B attempts to track the magnetic field signal 872B between various times in the cycle, for example, between times t_7 and t_8 , eventually achieving a positive peak of the magnetic field signal 872A at about time t_{11} , which may be within about three cycles of the magnetic field signal 872A. The PDAC signal 874B holds at other times.

[0117] It should be noted that the PDAC signal 872B is generated at times before achieving a positive peak of the magnetic field signal 872B (such times denoted by dashed line box 890B), but is inaccurate and does not represent the true motion detection information and so is not shown in FIG. 8. It should also be noted that in some embodiments, PDAC signal 872B is released just before positive peaks of magnetic field signal 872B (for example, just before positive peak 871B) and tracks the magnetic field signal 872B as it acquires the peak.

[0118] Similarly, an NDAC signal 876B, which may be representative of the NDAC signal 406 described in conjunction with FIG. 3, can acquire and track negative peaks (an example of which is designated by reference numeral 881B). The NDAC signal 876B attempts to track the magnetic field signal 872B between various times in the cycle, for example, between times t_9 and t_{10} , eventually achieving a negative peak of the magnetic field signal 872B at about time t_{12} , which may also be within about three cycles of the magnetic field signal 872B. The NDAC signal 876B holds at other times.

[0119] It should be noted that the NDAC signal 876B is generated at times before achieving a negative peak of the magnetic field signal 872B (such times denoted by dashed line box 892B), but is inaccurate and does not represent the true motion detection information and so is not shown in FIG. 8. It should also be noted that in some embodiments, NDAC signal 876B is released just before negative peaks of magnetic field signal 872B (for example, just before negative peak 881B) and tracks the magnetic field signal 872B as it acquires the peak.

[0120] Another portion 800C of the graph 800 includes a tracking threshold detector output signal 745A representative of, for example, the tracking threshold detector output signal 245A output from tracking threshold detector 210A of FIG. 2. In operation, the tracking threshold detector output signal 745A is representative of the output of a comparator (as may be similar to comparator 218A described in conjunction with FIG. 2) coupled at a first input to the magnetic field signal 872A and at a second input to a tracking signal, as may be similar to the tracking signal 277A output from tracking circuit 216A and described in conjunction with FIG. 2.

[0121] The tracking threshold output signal 745A has edges 747A, 747B that align with positive and negative peaks, respectively, of the magnetic field signal 872A. It can be seen in FIG. 8 that at some time (e.g., at about t_6), edges of the tracking threshold output signal 745A will align to a peak-to-peak magnitude of the magnetic field signal 872A, at which time the tracking threshold detector can be said to be calibrated to the magnetic field signal 872A (i.e., the tracking threshold detector output signal 745A will accurately track the positive and negative peaks of the magnetic field signal 872A). The tracking threshold

output signal 745A is generated at times before it aligns to the peak-to-peak magnitude of the magnetic field signal 872A (such times denoted by dashed line box 893), but is not used and so is not shown in FIG. 8.

5 [0122] Portion 800C of the graph 800 also includes a tracking threshold detector output signal 745B representative of, for example, the tracking threshold detector output signal 245B output from tracking threshold detector 210B of FIG. 2. In operation, the tracking threshold detector output signal 745B is representative of the output of a comparator (as may be similar to comparator 218B described in conjunction with FIG. 2) coupled at a first
10 input to the magnetic field signal 872B and at a second input to a tracking signal, as may be similar to the tracking signal 277B output from tracking circuit 216B described in conjunction with FIG. 2.

[0123] Similarly to the above-described signal 745A, the tracking threshold output signal
15 745B has edges 757A, 757B that align with positive and negative peaks, respectively, of the magnetic field signal 872B. It can be seen in FIG. 8 that at some time (e.g., at about t_{12}), edges of the tracking threshold output signal 745B will correspond to a peak-to-peak magnitude of the magnetic field signal 872B, at which time the tracking threshold detector
20 can be said to be calibrated to the magnetic field signal 872B (i.e., the tracking threshold detector output signal 745B will accurately track the positive and negative peaks of the magnetic field signal 872B). The tracking threshold output signal 745B is generated at times before it aligns to the peak-to-peak magnitude of the magnetic field signal 872B (such times denoted by dashed line box 893), but is not used and so is not shown in FIG. 8.

25 [0124] In FIG. 8, triangular icons (an example of which is designated by reference numeral 877) are indicative of speed and direction of object movement. An edge rate or period of the tracking threshold detector output signals 745A, 745B indicative of a speed of object movement. In other words, higher edge rates correspond to relatively fast object movement and lower edge rates correspond to relatively slow object movement. In embodiments in
30 which the object is a rotating gear, signal frequency is indicative of rotation speed of the gear.

[0125] In FIG. 8, the orientation of triangular icons 877 is indicative of a direction of object movement. As can be seen in graph 800, a first triangular icon 877A is shown in phantom relief to indicate that although the directional output is generated it is inaccurate and so the directional information may be generated from the predetermined threshold detectors. The other icons (for example, icon designated by reference numeral 877B) are oriented toward the right-hand side of the paper. As may be the same or similar to the circuit arrangement described above in conjunction with FIG. 2, the first and second tracking threshold detector output signals 745A, 745B are responsive to object movement relative to offset magnetic field sensing elements (such as magnetic field sensing elements 204A, 204B). Accordingly, a relative phase sequence of rising and falling edges of the signal 745A, 745B is representative of object movement direction.

[0126] Successive edge 760C and edge 760B may be used to accurately determine and update the direction of object movement (as can be seen by triangular icon 877B and all successive icons). In embodiments in which the object is a rotating gear, icon direction is indicative of clockwise or counter-clockwise rotational movement of the gear.

[0127] Referring again to FIGS. 7 and 8, it can be seen that correct object movement information (in particular, direction of object movement) can be generated at a time near circuit start up or power up at time t_0 using the predetermined threshold detector output signal (740A, 740B). For example, correct object movement direction information using the predetermined threshold detector output signal (740A, 740B) can be generated quickly after time t_0 at time t_{01} . The correct object movement direction information using the tracking threshold detector output signal (745A, 745B) can be generated later than time t_{01} at time t_{02} . At least a portion of the time difference can be attributed to the time required to calibrate the tracking threshold detectors. In contrast, the predetermined threshold detectors can generate object movement direction information whenever the magnetic field signal crosses the predetermined threshold values (e.g., 773A, 773B or 773A, 773C), which can occur relatively soon after a start up or power up period of the circuit.

[0128] Referring now to FIG. 9, first graph 900A has a horizontal axis with a scale in arbitrary units of time and a vertical axis in arbitrary units of voltage. Graph 900A includes a first predetermined threshold detector output signal 940A representative of, for example,

the predetermined threshold detector output signal 240A output from the predetermined threshold detector 220A of FIG. 2, and a second predetermined threshold detector output signal 940B representative of, for example, the predetermined threshold detector output signal 240B output from the predetermined threshold detector 220B of circuit 200 of FIG. 2.

5 Graph 900A also includes a first tracking threshold detector output signal 945A representative of, for example, the tracking threshold detector output signal 245A output from the tracking threshold detector 210A of FIG. 2, and a second tracking threshold detector output signal 945B representative of, for example, the tracking threshold detector output signal 245B output from the tracking threshold detector 210B of circuit 200 of FIG.

10 2.

[0129] A second graph 900B has a horizontal axis with a scale in arbitrary units of time and a vertical axis to indicate selected output information (an example of which is designated by reference number 955) related to one of the signals 940A, 940B, 945A, 945B of graph
15 900A. The selected output information 955 relates to movement of an object, as may be the same or similar to object movement information (e.g., speed and direction of object movement) described above in conjunction with FIG. 7 and FIG. 8.

[0130] For example, at time t_{21} , the selected object speed information 955A is related to the
20 signal 940A and at time t_{24} the selected object speed information 955B is related to signal 945A. Here, during circuit start up or power up, an output signal selector (as may be the same or similar to output selector 250 of circuit 200 of FIG. 2) selects one of the predetermined threshold detector output signals (e.g., the first predetermined threshold detector output signal 940A) to generate speed information and at time t_{24} selects one of the
25 tracking threshold detector output signal (e.g., the first tracking threshold detector 945A) to generate speed information.

[0131] At time t_{22} , the selected object direction information 955C is derived from signals 940A, 940B and at time t_{23} the selected object direction information 955D is derived from
30 signals 945A, 945B. Here, during circuit start up or power up, the output signal selector selects relative phases of the predetermined threshold detector output signals (e.g., predetermined threshold detector output signals 940A, 940B) to derive direction information and at time t_{23} selects relative phases of the tracking threshold detector output

signals (e.g., the tracking threshold detector signals 945A, 945B) to derive direction information. Time t_{23} (i.e., a time when output selector 250 of circuit 200 of FIG. 2 switches from using the predetermined threshold detectors 220A, 220B to using the tracking threshold detectors 210A, 210B) may correspond to a predetermined condition including, but not limited to, a calibration time of a circuit and/or a predetermined number of cycles of one of the signals 940A, 940B, 945A, 945B. Triangular icons 977 represent object direction information output by the output signal selector related to the first and second predetermined threshold detector output signals 940A, 940B, and triangular icons 979 represent object direction information output by the output signal selector related to the first and second tracking threshold detector output signals 945A, 945B.

[0132] It will be appreciated that, in order to obtain a rapid determination of direction of movement, two predetermined threshold detectors should be used, so that a relative phase can be rapidly determined between the output signals of the two predetermined threshold detectors. However, use of only one predetermined threshold detector as in FIG. 1 can still provide advantages, for example, a more rapid determination of object speed of movement (see, e.g., selected output information 955 beginning at time t_{21}).

[0133] While particular numbers of cycles, particular times, and other particular parameters are described above, it will be appreciated that other numbers of cycles, other times, and other particular parameters can be used.

[0134] It should be appreciated that a circuit as described herein may be used in applications in which it is desired, needed, or necessary to generate fast speed and/or direction information in sensor applications including, but not limited to, automotive engine management applications.

[0135] All publications and references cited herein are expressly incorporated herein by reference in their entirety.

[0136] Having described embodiments of the invention, it will now become apparent to one of ordinary skill in the art that other embodiments incorporating these concepts may be used. It is felt therefore that these embodiments should not be limited to disclosed embodiments, but rather should be limited only by the spirit and scope of the appended
5 claims.

What is claimed is:

CLAIMS

1. A circuit responsive to movement of an object, comprising:
- a magnetic field sensing element operative to provide a magnetic field signal proportional to a magnetic field associated with the object;
 - a predetermined threshold detector comprising:
 - a comparator having a first input responsive to the magnetic field signal, a second input responsive to a predetermined threshold, and an output at which is provided a predetermined threshold detector output signal;
 - a tracking threshold detector comprising:
 - a tracking circuit coupled to receive the magnetic field signal and configured to track positive and negative peaks of the magnetic field signal and to generate a tracking signal; and
 - a comparator having a first input responsive to the magnetic field signal, a second input responsive to an input signal related to the tracking signal, and an output at which is provided a tracking threshold detector output signal; and
 - an output signal selector having a first input responsive to the tracking threshold detector output signal, a second input responsive to the predetermined threshold detector output signal, and configured to generate a circuit output signal related to at least one of the predetermined threshold detector output signal or the tracking threshold detector output signal based upon a predetermined condition.
2. The circuit of claim 1, wherein the predetermined condition is related to a predetermined number of cycles of the magnetic field signal.
3. The circuit of claim 1, wherein the predetermined condition is related to a predetermined number of cycles of the predetermined threshold detector output signal.
4. The circuit of claim 1, wherein the predetermined condition corresponds to a predetermined time.
5. The circuit of claim 1, further comprising:

1 at least one of an automatic gain control coupled to the magnetic field sensing
2 element and configured to process the magnetic field signal, wherein the predetermined
3 condition corresponds to a condition of the automatic gain control, or an automatic offset
4 adjustment coupled to the magnetic field sensing element and configured to process the
5 magnetic field signal, wherein the predetermined condition corresponds to a condition of the
6 automatic offset adjustment.

7
8 6. The circuit of claim 1, wherein the output signal selector is further configured to
9 generate the circuit output signal related to the predetermined threshold detector output
10 signal during a calibration time period of the tracking threshold detector and to generate the
11 circuit output signal related to the tracking threshold detector output signal after the
12 calibration time period wherein the predetermined condition corresponds to the end of the
13 calibration time period.

14
15 7. The circuit of claim 1, wherein the magnetic field sensing element is a first pair of
16 magnetic field sensing elements, the magnetic field signal is a first magnetic field signal,
17 and the predetermined threshold detector is a first predetermined threshold detector
18 responsive to the first magnetic field signal and operative to provide a first predetermined
19 threshold detector output signal having a first predetermined threshold detector phase, the
20 circuit further comprising:

21 a second pair of magnetic field sensing elements operative to provide a second
22 magnetic field signal; and

23 a second predetermined threshold detector comprising:

24 a comparator having a first input responsive to the second magnetic field
25 signal, a second input responsive to the predetermined threshold, and an output at
26 which is provided a second predetermined threshold detector output signal having a
27 second predetermined threshold detector phase,
28 wherein the signal selector further comprises a third input responsive to the second
29 predetermined threshold detector output signal, wherein a difference between the
30 first and second predetermined threshold detector phases is indicative of a
31 movement direction of the object.

32
33 8. The circuit of claim 7, wherein the predetermined condition is related to a

1 predetermined number of cycles of one of the first or second magnetic field signals.

2
3 9. The circuit of claim 7, wherein the predetermined condition is related to a
4 predetermined number of cycles of one of the first or second predetermined threshold
5 detector output signals.

6
7 10. The circuit of claim 7, wherein the predetermined condition corresponds to a
8 predetermined time.

9
10 11. The circuit of claim 7, further comprising:

11 at least one of an automatic gain control coupled to one of the first pair or the second
12 pair of magnetic field sensing elements and configured to process a corresponding one of
13 the first or second magnetic field signals, wherein the predetermined condition corresponds
14 to a condition of the automatic gain control, or an automatic offset adjustment coupled to
15 one of the first pair or the second pair of magnetic field sensing elements and configured to
16 process a corresponding one of the first or second magnetic field signals, wherein the
17 predetermined condition corresponds to a condition of the automatic gain control.

18
19 12. The circuit of claim 1, wherein the magnetic field sensing element is a first pair of
20 magnetic field sensing elements and the magnetic field signal is a first magnetic field signal,
21 and the tracking threshold detector is a first tracking threshold detector responsive to the
22 first magnetic field signal and operative to provide a first tracking threshold detector output
23 signal having a frequency indicative of movement speed of the object and a first tracking
24 threshold detector phase, the circuit further comprising:

25 a second pair of magnetic field sensing elements operative to provide a
26 second magnetic field signal; and

27 a second tracking threshold detector comprising:

28 a tracking circuit coupled to receive the second magnetic field signal
29 and configured to track positive and negative peaks of the second magnetic
30 field signal and to generate a second tracking signal; and

31 a comparator having a first input responsive to the second magnetic
32 field signal, a second input responsive to an input signal related to the second
33 tracking signal, and an output at which is provided a second tracking

threshold detector output signal having a second tracking threshold detector phase wherein the signal selector further comprises a third input responsive to the second tracking threshold detector output signal, wherein a difference between the first and second tracking threshold detector phases is indicative of a movement direction of the object.

13. The circuit of claim 12, wherein the predetermined condition is related to a predetermined number of cycles of one of the first or second magnetic field signals.

14. The circuit of claim 12, wherein the predetermined condition is related to a predetermined number of cycles of one of the first or second tracking threshold detector output signals.

15. The circuit of claim 12, wherein the predetermined condition corresponds to a predetermined time.

16. The circuit of claim 12, further comprising:

at least one of an automatic gain control coupled to one of the first pair or the second pair of magnetic field sensing elements and configured to process a corresponding one of the first or second magnetic field signals, wherein the predetermined condition corresponds to a condition of the automatic gain control, or an automatic offset adjustment coupled to one of the first pair or the second pair of magnetic field sensing elements and configured to process a corresponding one of the first or second magnetic field signals, wherein the predetermined condition corresponds to a condition of the automatic offset adjustment.

17. The circuit of claim 12, wherein the predetermined threshold detector is a first predetermined threshold detector responsive to the first magnetic field signal and the first predetermined threshold detector comparator is responsive to a first predetermined threshold and is operative to provide a first predetermined threshold detector output signal having a frequency indicative of movement speed of the object and a first predetermined threshold detector phase, the circuit further comprising:

a second predetermined threshold detector comprising:

a second comparator circuit having an input responsive to the second

1 magnetic field signal and another input responsive to a second predetermined
2 threshold and operative to provide a second predetermined threshold detector output
3 signal having a second predetermined threshold detector phase wherein the signal
4 selector further comprises a fourth input responsive to the second predetermined
5 threshold detector output signal, wherein a difference between the first and second
6 predetermined threshold detector phases is indicative of a movement direction of the
7 object.
8

9 18. The circuit of claim 17, wherein at least one of the first or second predetermined
10 threshold detectors includes a Schmitt trigger.
11

12 19. The circuit of claim 17, wherein the output signal selector further includes a third input
13 responsive to the second tracking threshold detector output signal and a fourth input
14 responsive to the second predetermined threshold detector output signal and is further
15 configured to provide the circuit output signal corresponding to a combination of the first
16 and second tracking threshold detector output signals or a combination of the first and
17 second predetermined threshold detector output signals based upon the predetermined
18 condition.
19

20 20. The circuit of claim 17, wherein the predetermined condition is related to a
21 predetermined number of cycles of one of the first or second magnetic field signals.
22

23 21. The circuit of claim 17, wherein the predetermined condition is related to a
24 predetermined number of cycles of one of the first predetermined threshold detector output
25 signal, second predetermined threshold detector output signal, first tracking threshold
26 detector output signal, or second tracking threshold detector output signal.
27

28 22. The circuit of claim 17, wherein the predetermined condition corresponds to a
29 predetermined time.
30

31 23. The circuit of claim 17, further comprising:

32 at least one of an automatic gain control coupled to one of the first pair or the second
33 pair of magnetic field sensing elements and configured to process a corresponding one of

1 the first or second magnetic field signals, wherein the predetermined condition corresponds
2 to a condition of the automatic gain control, or an automatic offset adjustment coupled to
3 one of the first pair or the second pair of magnetic field sensing elements and configured to
4 process a corresponding one of the first or second magnetic field signals, wherein the
5 predetermined condition corresponds to a condition of the automatic offset adjustment.

6
7 24. A circuit responsive to movement of an object, comprising:

8 a first pair of magnetic field sensing elements operative to provide a first magnetic
9 field signal proportional to a magnetic field associated with the object;

10 a second pair of magnetic field sensing elements operative to provide a second
11 magnetic field signal proportional to the magnetic field;

12 a first predetermined threshold detector including a first comparator circuit having
13 an input responsive to the first magnetic field signal and another input responsive to a first
14 predetermined threshold and an output at which is provided a first predetermined threshold
15 detector output signal having a frequency indicative of movement speed of the object and a
16 first predetermined threshold detector phase;

17 a second predetermined threshold detector including a second comparator circuit
18 having an input responsive to the second magnetic field signal and another input responsive
19 to a second predetermined threshold and an output at which is provided a second
20 predetermined threshold detector output signal having a second predetermined threshold
21 detector phase, wherein a difference between the first and second predetermined threshold
22 detector phases is indicative of a movement direction of the object;

23 a first tracking threshold detector responsive to the first magnetic field signal and an
24 output at which is provided a first tracking threshold detector output signal having a
25 frequency indicative of a tracking threshold speed of the object and a first tracking threshold
26 detector phase;

27 a second tracking threshold detector responsive to the second magnetic field signal
28 and an output at which is provided a second tracking threshold detector output signal having
29 a second tracking threshold detector phase different than the first tracking threshold detector
30 phase, wherein a difference between the first and second tracking threshold detector phases
31 is indicative of the movement direction of the object; and

32 an output signal selector coupled to receive the first predetermined threshold
33 detector output signal, the second predetermined threshold detector output signal, the first

1 tracking threshold detector output signal, and the second tracking threshold detector output
2 signal and configured to generate a circuit output signal related to at least one of the
3 received detector signals based upon a predetermined condition.

4
5 25. The circuit of claim 24, wherein the predetermined condition is related to a
6 predetermined number of cycles of one of the first or second magnetic field signals.

7
8 26. The circuit of claim 24, wherein the predetermined condition is related to a
9 predetermined number of cycles of one of the first predetermined threshold detector output
10 signal, second predetermined threshold detector output signal, first tracking threshold
11 detector output signal, or second tracking threshold detector output signal.

12
13 27. The circuit of claim 24, wherein the predetermined condition corresponds to a
14 predetermined time.

15
16 28. The circuit of claim 24, further comprising:
17 at least one of an automatic gain control coupled to one of the first pair or the second
18 pair of magnetic field sensing elements and configured to process a corresponding one of
19 the first or second magnetic field signals, wherein the predetermined condition corresponds
20 to a condition of the automatic gain control, or an automatic offset adjustment coupled to
21 one of the first pair or the second pair of magnetic field sensing elements and configured to
22 process a corresponding one of the first or second magnetic field signals, wherein the
23 predetermined condition corresponds to a condition of the automatic offset adjustment.

24
25 29. A method of detecting a movement of an object, comprising:
26 generating a magnetic field signal proportional to a magnetic field associated with
27 the object;
28 generating a tracking signal responsive to the magnetic field signal to track positive
29 and negative peaks of the magnetic field signal;
30 generating a predetermined threshold output signal responsive to the magnetic field
31 signal and to a predetermined threshold;
32 generating a tracking threshold output signal responsive to the magnetic field signal
33 and to the tracking signal; and

1 providing an overall output signal related to a selected one of the predetermined
2 threshold output signal or the tracking threshold output signal based upon a predetermined
3 condition.

4
5 30. The method of claim 29, wherein the predetermined condition is related to a
6 predetermined number of cycles of the magnetic field signal.

7
8 31. The method of claim 29, wherein the predetermined condition is related to a
9 predetermined number of cycles of the predetermined threshold output signal.

10
11 32. The method of claim 29, wherein the predetermined condition corresponds to a
12 predetermined time.

13
14 33. The method of claim 29, further comprising:

15 processing the magnetic field signal using at least one of an automatic gain control,
16 wherein the predetermined condition corresponds to a condition of the automatic gain
17 control, or an automatic adjustment control, wherein the predetermined condition
18 corresponds to a condition of the automatic adjustment control.

19
20 34. The method of claim 29, wherein said providing the overall output signal further
21 comprises:

22 selecting the overall output signal to be related to the predetermined threshold output
23 signal during a calibration time period; and

24 selecting the overall output signal to be related to the tracking threshold output
25 signal after the calibration time period, wherein the predetermined condition corresponds to
26 the end of the calibration time period.

27
28 35. The method of claim 29, wherein said magnetic field signal is a first magnetic field
29 signal proportional to a magnetic field of the object at a first position, said tracking signal is
30 a first tracking signal responsive to the first magnetic field signal, said tracking threshold
31 output signal is a first tracking threshold output signal responsive to the first magnetic field
32 signal and to the first tracking signal, wherein the first tracking threshold output signal has a
33 frequency indicative of a movement speed of the object and a first tracking threshold output

1 signal phase, and said predetermined threshold output signal is a first predetermined
2 threshold output signal responsive to the first magnetic field signal and to a first
3 predetermined threshold, the first predetermined threshold output signal having a frequency
4 indicative of the movement speed of the object and having a first predetermined threshold
5 output signal phase, the method further comprising:

6 generating a second magnetic field signal proportional to a second magnetic field
7 associated with the object at a second position offset from the first position;

8 generating a second tracking signal responsive to the second magnetic field signal to
9 track positive and negative peaks of the second magnetic field signal;

10 generating a second tracking threshold output signal responsive to the second
11 magnetic field signal and to the second tracking signal and having a second tracking
12 threshold output signal phase, a difference of the first and second tracking threshold output
13 signal phases indicative of a movement direction of the object; and

14 generating a second predetermined threshold output signal responsive to the second
15 magnetic field signal and to a second predetermined threshold and having a second
16 predetermined threshold output signal phase, a difference of the first and second output
17 signal phases indicative of movement direction of the object, wherein said overall output
18 signal is further related to a selected one of a combination of the first and second
19 predetermined threshold output signals or a combination of the first and second tracking
20 threshold output signals based upon the predetermined condition.

21
22 36. The method of claim 35, wherein the predetermined condition is related to a
23 predetermined number of cycles of one of the first or second magnetic field signals.

24
25 37. The method of claim 35, wherein the predetermined condition is related to a
26 predetermined number of cycles of one of the first predetermined threshold detector output
27 signal, second predetermined threshold detector output signal, first tracking threshold
28 detector output signal, or second tracking threshold detector output signal.

29
30 38. The method of claim 35, wherein the predetermined condition corresponds to a
31 predetermined time.

32
33 39. The method of claim 35, further comprising:

1 processing one of the first or second magnetic field signals using at least one of an
2 automatic gain control, wherein the predetermined condition corresponds to a condition of
3 the automatic gain control, or an automatic offset adjustment, wherein the predetermined
4 condition corresponds to a condition of the automatic offset adjustment.
5

AMENDED CLAIMS

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1. A circuit responsive to movement of an object, comprising:
- a magnetic field sensing element operative to provide a magnetic field signal proportional to a magnetic field associated with the object;
 - a predetermined threshold detector comprising:
 - a comparator having a first input responsive to the magnetic field signal, a second input responsive to a predetermined threshold, and an output at which is provided a predetermined threshold detector output signal, wherein the predetermined threshold detector output signal is indicative of movement of the object;
 - a tracking threshold detector comprising:
 - a tracking circuit coupled to receive the magnetic field signal and configured to track positive and negative peaks of the magnetic field signal and to generate a tracking signal; and
 - a comparator having a first input responsive to the magnetic field signal, a second input responsive to an input signal related to the tracking signal, and an output at which is provided a tracking threshold detector output signal; and
 - an output signal selector having a first input responsive to the tracking threshold detector output signal, a second input responsive to the predetermined threshold detector output signal, and configured to generate a circuit output signal related to at least one of the predetermined threshold detector output signal or the tracking threshold detector output signal based upon a predetermined condition, wherein the predetermined condition is related to at least one of:
 - a predetermined number of cycles of the magnetic field signal or the predetermined threshold detector output signal;
 - a predetermined time;
 - a condition of an automatic gain control or an automatic offset adjustment; or
 - the end of a calibration time period.

1 7. The circuit of claim 1, wherein the magnetic field sensing element is a first pair of
2 magnetic field sensing elements, the magnetic field signal is a first magnetic field signal,
3 and the predetermined threshold detector is a first predetermined threshold detector
4 responsive to the first magnetic field signal and operative to provide a first predetermined
5 threshold detector output signal having a first predetermined threshold detector phase, the
6 circuit further comprising:

7 a second pair of magnetic field sensing elements operative to provide a second
8 magnetic field signal; and

9 a second predetermined threshold detector comprising:

10 a comparator having a first input responsive to the second magnetic field
11 signal, a second input responsive to the predetermined threshold, and an output at
12 which is provided a second predetermined threshold detector output signal having a
13 second predetermined threshold detector phase,
14 wherein the signal selector further comprises a third input responsive to the second
15 predetermined threshold detector output signal, wherein a difference between the
16 first and second predetermined threshold detector phases is indicative of a
17 movement direction of the object.
18

19 8. The circuit of claim 7, wherein the predetermined condition is related to a
20 predetermined number of cycles of one of the first or second magnetic field signals.
21

22 9. The circuit of claim 7, wherein the predetermined condition is related to a
23 predetermined number of cycles of one of the first or second predetermined threshold
24 detector output signals.
25

26 10. The circuit of claim 7, wherein the predetermined condition corresponds to a
27 predetermined time.
28

29 11. The circuit of claim 7, further comprising:

30 at least one of an automatic gain control coupled to one of the first pair or the second
31 pair of magnetic field sensing elements and configured to process a corresponding one of
32 the first or second magnetic field signals, wherein the predetermined condition corresponds
33 to a condition of the automatic gain control, or an automatic offset adjustment coupled to

1 one of the first pair or the second pair of magnetic field sensing elements and configured to
2 process a corresponding one of the first or second magnetic field signals, wherein the
3 predetermined condition corresponds to a condition of the automatic gain control.

4
5 12. The circuit of claim 1, wherein the magnetic field sensing element is a first pair of
6 magnetic field sensing elements and the magnetic field signal is a first magnetic field signal,
7 and the tracking threshold detector is a first tracking threshold detector responsive to the
8 first magnetic field signal and operative to provide a first tracking threshold detector output
9 signal having a frequency indicative of movement speed of the object and a first tracking
10 threshold detector phase, the circuit further comprising:

11 a second pair of magnetic field sensing elements operative to provide a
12 second magnetic field signal; and

13 a second tracking threshold detector comprising:

14 a tracking circuit coupled to receive the second magnetic field signal
15 and configured to track positive and negative peaks of the second magnetic
16 field signal and to generate a second tracking signal; and

17 a comparator having a first input responsive to the second magnetic
18 field signal, a second input responsive to an input signal related to the second
19 tracking signal, and an output at which is provided a second tracking
20 threshold detector output signal having a second tracking threshold detector
21 phase wherein the signal selector further comprises a third input responsive
22 to the second tracking threshold detector output signal, wherein a difference
23 between the first and second tracking threshold detector phases is indicative
24 of a movement direction of the object.

25
26 13. The circuit of claim 12, wherein the predetermined condition is related to a
27 predetermined number of cycles of one of the first or second magnetic field signals.

28
29 14. The circuit of claim 12, wherein the predetermined condition is related to a
30 predetermined number of cycles of one of the first or second tracking threshold detector
31 output signals.

32
33 15. The circuit of claim 12, wherein the predetermined condition corresponds to a

1 predetermined time.

2
3 16. The circuit of claim 12, further comprising:

4 at least one of an automatic gain control coupled to one of the first pair or the second
5 pair of magnetic field sensing elements and configured to process a corresponding one of
6 the first or second magnetic field signals, wherein the predetermined condition corresponds
7 to a condition of the automatic gain control, or an automatic offset adjustment coupled to
8 one of the first pair or the second pair of magnetic field sensing elements and configured to
9 process a corresponding one of the first or second magnetic field signals, wherein the
10 predetermined condition corresponds to a condition of the automatic offset adjustment.

11
12 17. The circuit of claim 12, wherein the predetermined threshold detector is a first
13 predetermined threshold detector responsive to the first magnetic field signal and the first
14 predetermined threshold detector comparator is responsive to a first predetermined
15 threshold and is operative to provide a first predetermined threshold detector output signal
16 having a frequency indicative of movement speed of the object and a first predetermined
17 threshold detector phase, the circuit further comprising:

18 a second predetermined threshold detector comprising:

19 a second comparator circuit having an input responsive to the second
20 magnetic field signal and another input responsive to a second predetermined
21 threshold and operative to provide a second predetermined threshold detector output
22 signal having a second predetermined threshold detector phase wherein the signal
23 selector further comprises a fourth input responsive to the second predetermined
24 threshold detector output signal, wherein a difference between the first and second
25 predetermined threshold detector phases is indicative of a movement direction of the
26 object.

27
28 18. The circuit of claim 17, wherein at least one of the first or second predetermined
29 threshold detectors includes a Schmitt trigger.

30
31 19. The circuit of claim 17, wherein the output signal selector further includes a third input
32 responsive to the second tracking threshold detector output signal and a fourth input
33 responsive to the second predetermined threshold detector output signal and is further

1 configured to provide the circuit output signal corresponding to a combination of the first
2 and second tracking threshold detector output signals or a combination of the first and
3 second predetermined threshold detector output signals based upon the predetermined
4 condition.
5

6 20. The circuit of claim 17, wherein the predetermined condition is related to a
7 predetermined number of cycles of one of the first or second magnetic field signals.
8

9 21. The circuit of claim 17, wherein the predetermined condition is related to a
10 predetermined number of cycles of one of the first predetermined threshold detector output
11 signal, second predetermined threshold detector output signal, first tracking threshold
12 detector output signal, or second tracking threshold detector output signal.
13

14 22. The circuit of claim 17, wherein the predetermined condition corresponds to a
15 predetermined time.
16

17 23. The circuit of claim 17, further comprising:

18 at least one of an automatic gain control coupled to one of the first pair or the second
19 pair of magnetic field sensing elements and configured to process a corresponding one of
20 the first or second magnetic field signals, wherein the predetermined condition corresponds
21 to a condition of the automatic gain control, or an automatic offset adjustment coupled to
22 one of the first pair or the second pair of magnetic field sensing elements and configured to
23 process a corresponding one of the first or second magnetic field signals, wherein the
24 predetermined condition corresponds to a condition of the automatic offset adjustment.
25
26
27

28 29. A method of detecting a movement of an object, comprising:

29 generating a magnetic field signal proportional to a magnetic field associated with
30 the object;

31 generating a tracking signal responsive to the magnetic field signal to track positive
32 and negative peaks of the magnetic field signal;

33 generating a predetermined threshold output signal responsive to the magnetic field

1 signal and to a predetermined threshold, wherein the predetermined threshold output signal
2 is indicative of movement of the object;

3 generating a tracking threshold output signal responsive to the magnetic field signal
4 and to the tracking signal; and

5 providing an overall output signal related to a selected one of the predetermined
6 threshold output signal or the tracking threshold output signal based upon a predetermined
7 condition that is related to at least one of:

8 a predetermined number of cycles of the magnetic field signal or the
9 predetermined threshold detector output signal;

10 a predetermined time;

11 a condition of an automatic gain control or an automatic offset adjustment; or
12 the end of a calibration time period.

13
14 35. The method of claim 29, wherein said magnetic field signal is a first magnetic field
15 signal proportional to a magnetic field of the object at a first position, said tracking signal is
16 a first tracking signal responsive to the first magnetic field signal, said tracking threshold
17 output signal is a first tracking threshold output signal responsive to the first magnetic field
18 signal and to the first tracking signal, wherein the first tracking threshold output signal has a
19 frequency indicative of a movement speed of the object and a first tracking threshold output
20 signal phase, and said predetermined threshold output signal is a first predetermined
21 threshold output signal responsive to the first magnetic field signal and to a first
22 predetermined threshold, the first predetermined threshold output signal having a frequency
23 indicative of the movement speed of the object and having a first predetermined threshold
24 output signal phase, the method further comprising:

25 generating a second magnetic field signal proportional to a second magnetic field
26 associated with the object at a second position offset from the first position;

27 generating a second tracking signal responsive to the second magnetic field signal to
28 track positive and negative peaks of the second magnetic field signal;

29 generating a second tracking threshold output signal responsive to the second
30 magnetic field signal and to the second tracking signal and having a second tracking
31 threshold output signal phase, a difference of the first and second tracking threshold output
32 signal phases indicative of a movement direction of the object; and

33 generating a second predetermined threshold output signal responsive to the second

1 magnetic field signal and to a second predetermined threshold and having a second
2 predetermined threshold output signal phase, a difference of the first and second output
3 signal phases indicative of movement direction of the object, wherein said overall output
4 signal is further related to a selected one of a combination of the first and second
5 predetermined threshold output signals or a combination of the first and second tracking
6 threshold output signals based upon the predetermined condition.

7
8 36. The method of claim 35, wherein the predetermined condition is related to a
9 predetermined number of cycles of one of the first or second magnetic field signals.

10
11 37. The method of claim 35, wherein the predetermined condition is related to a
12 predetermined number of cycles of one of the first predetermined threshold detector output
13 signal, second predetermined threshold detector output signal, first tracking threshold
14 detector output signal, or second tracking threshold detector output signal.

15
16 38. The method of claim 35, wherein the predetermined condition corresponds to a
17 predetermined time.

18
19 39. The method of claim 35, further comprising:

20 processing one of the first or second magnetic field signals using at least one of an
21 automatic gain control, wherein the predetermined condition corresponds to a condition of
22 the automatic gain control, or an automatic offset adjustment, wherein the predetermined
23 condition corresponds to a condition of the automatic offset adjustment.

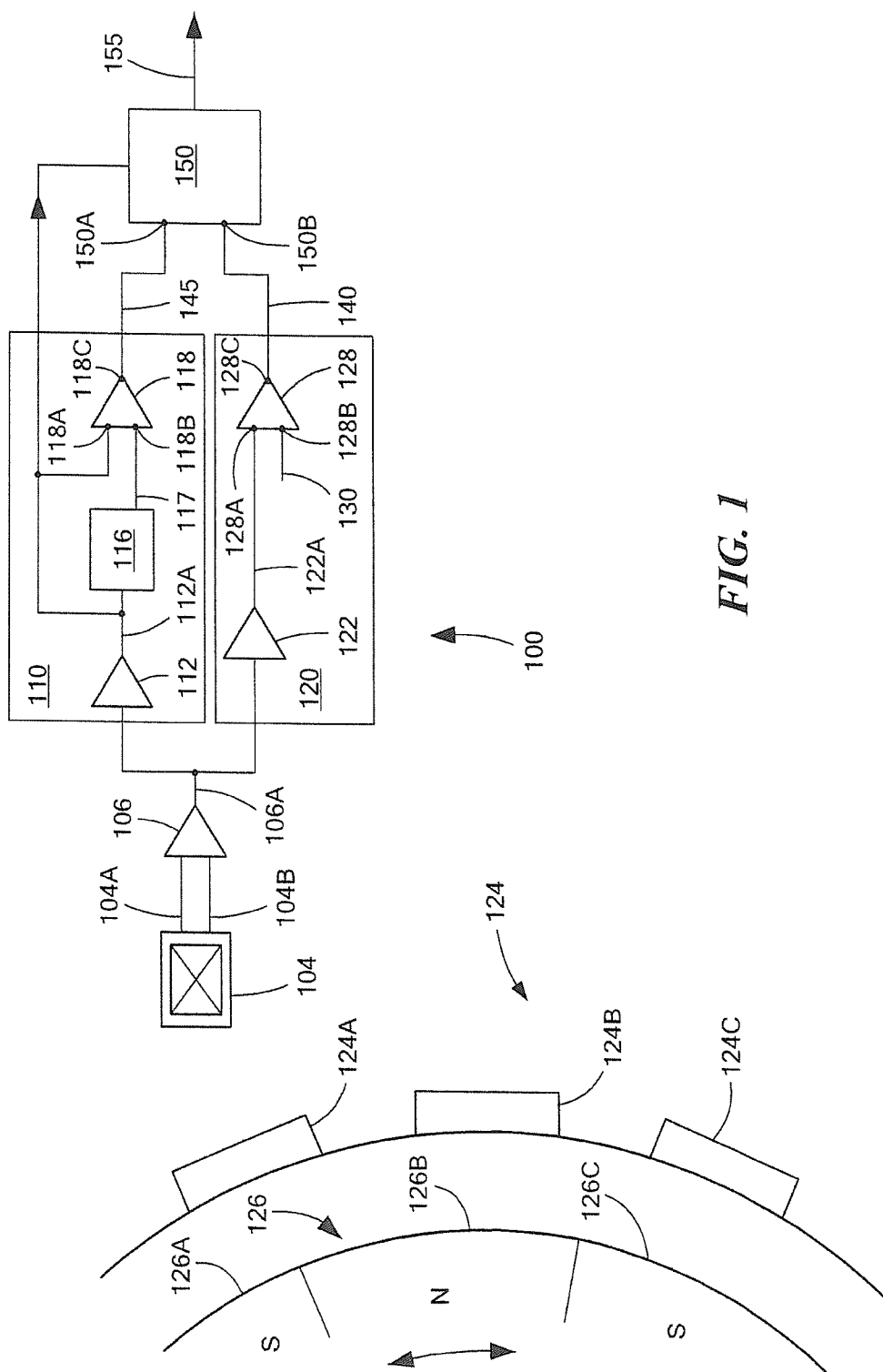


FIG. 1

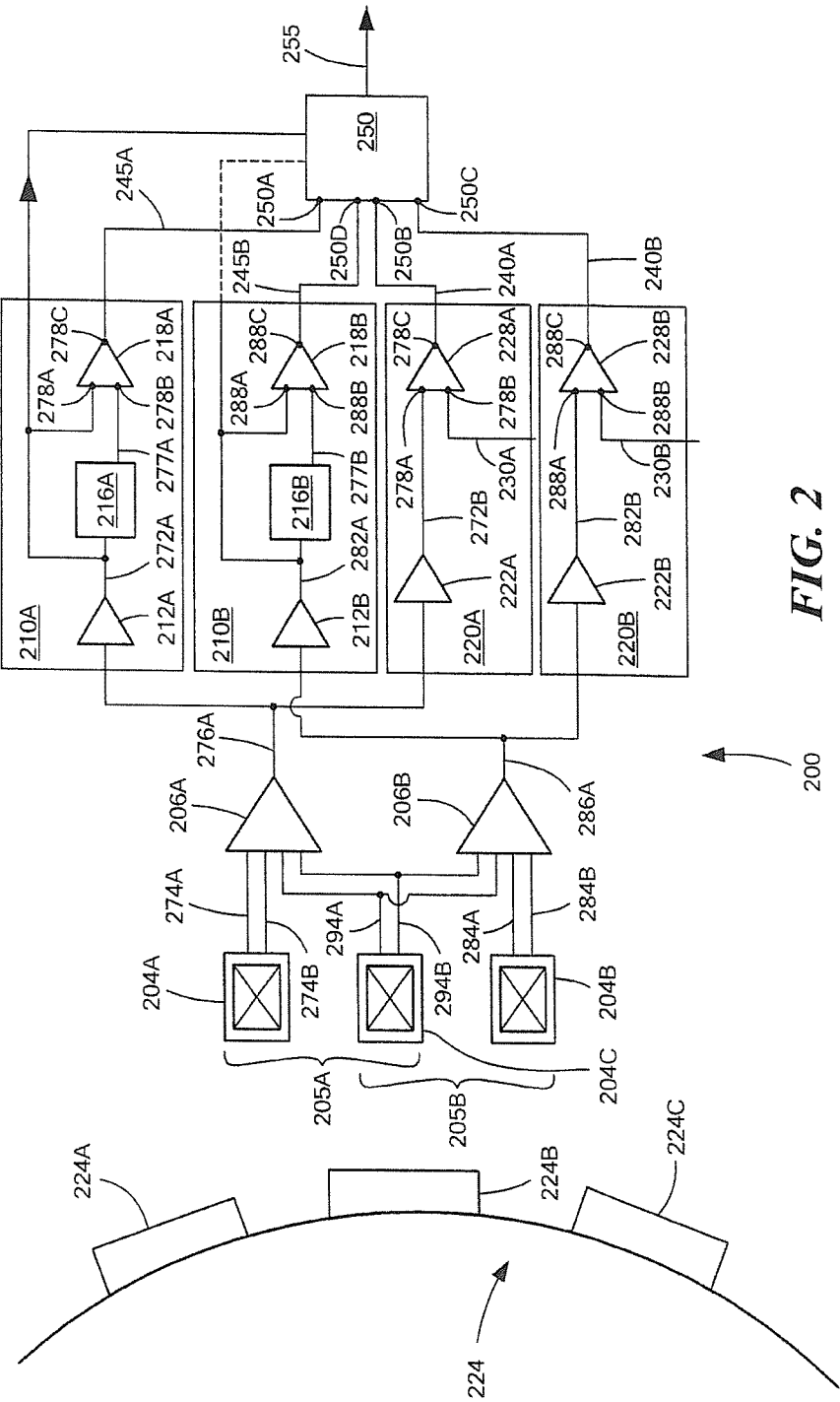
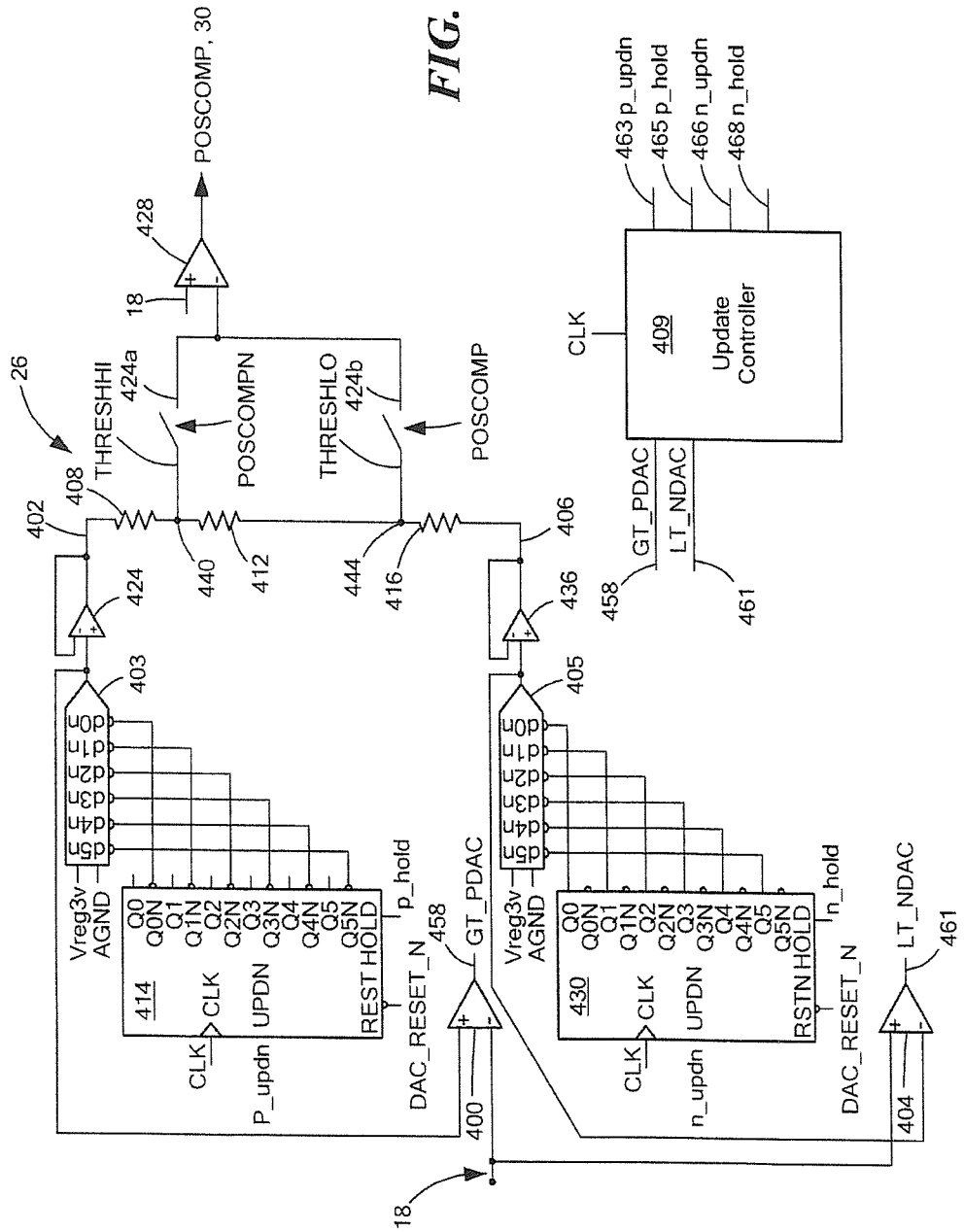
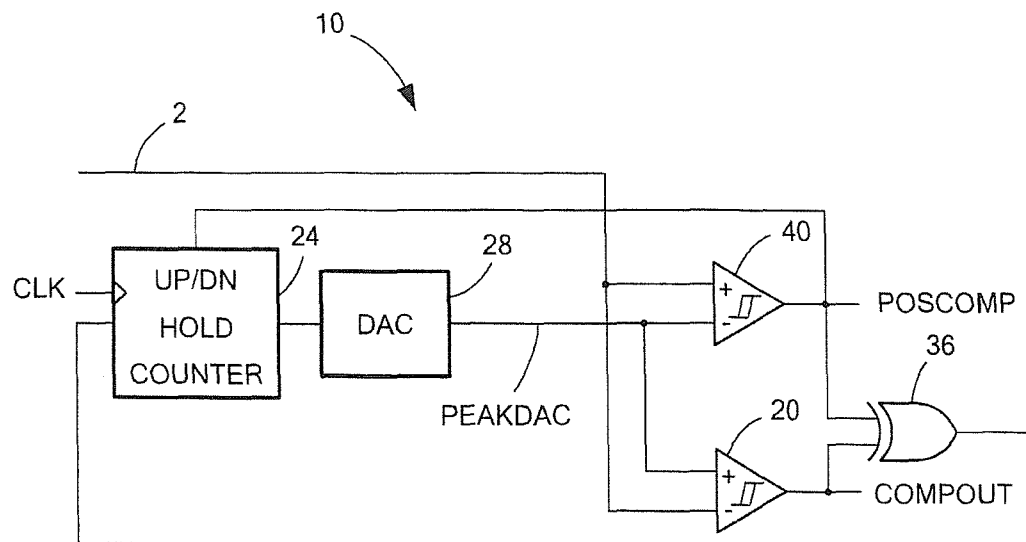
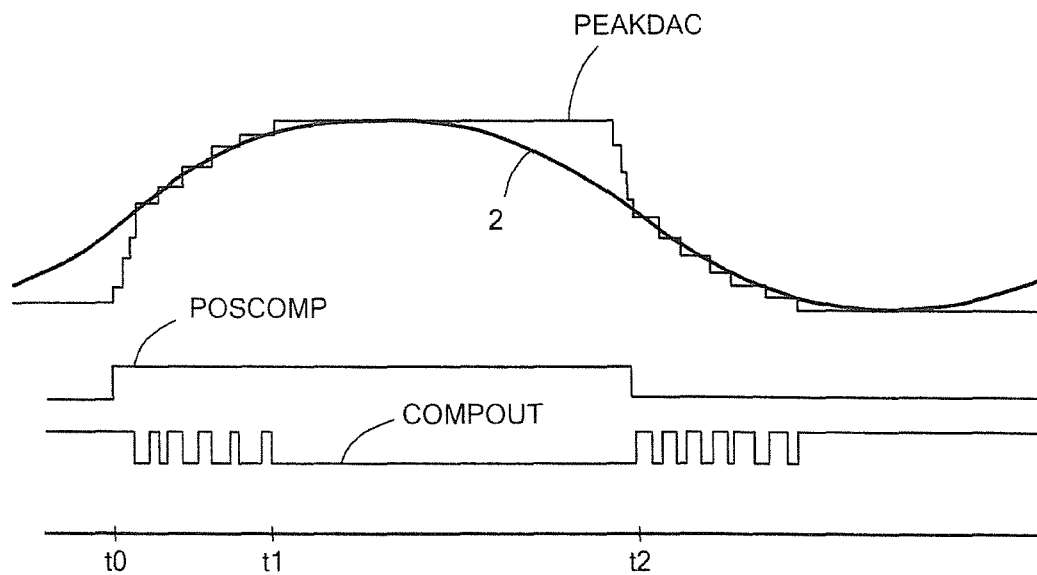


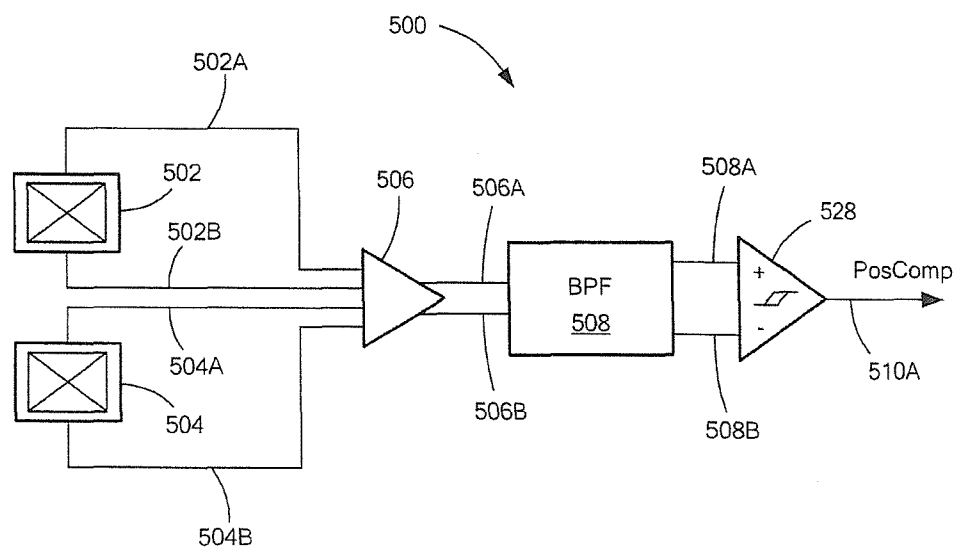
FIG. 3



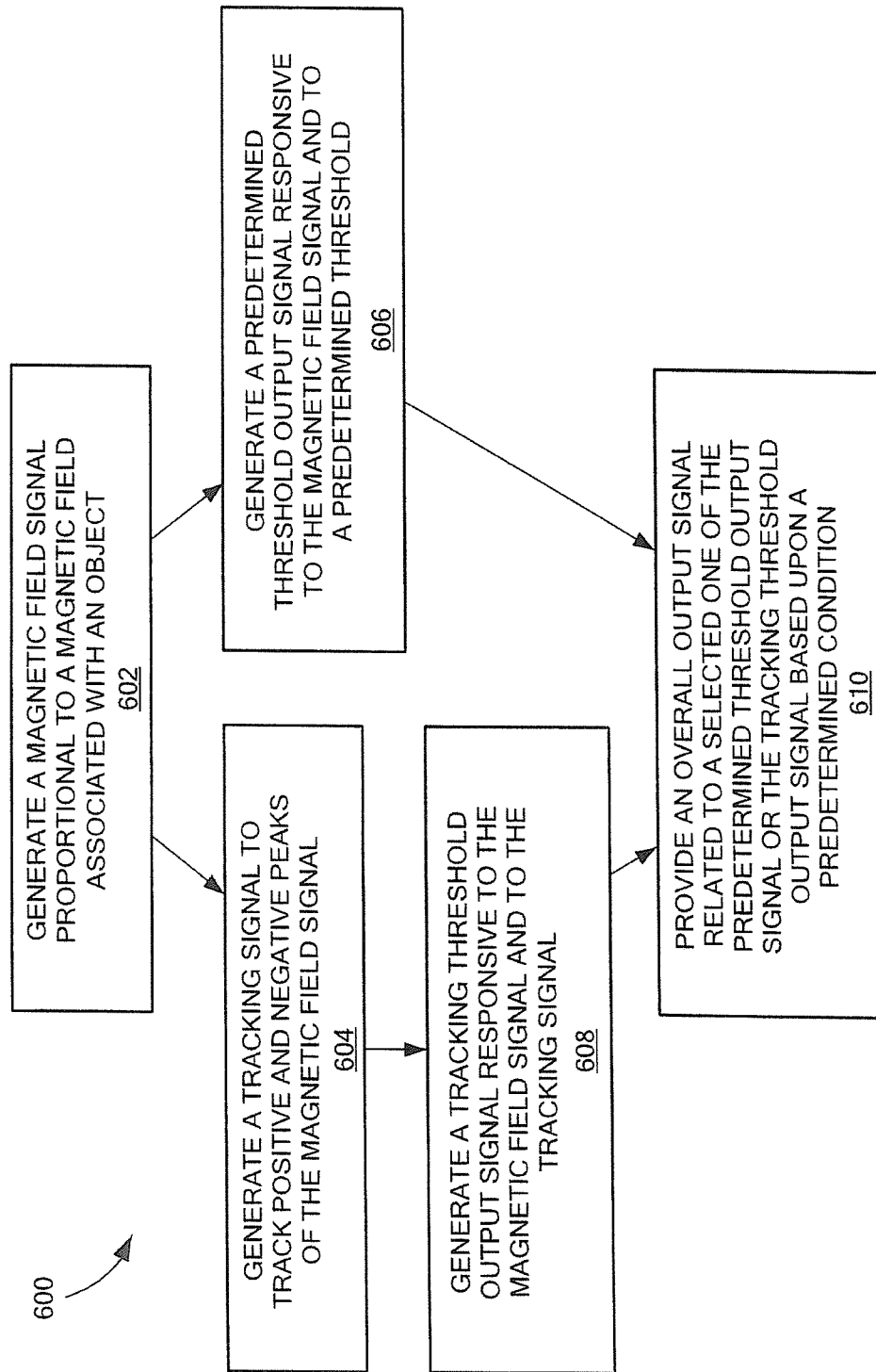
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**FIG. 4A****FIG. 4B**

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**FIG. 5**

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**FIG. 6**

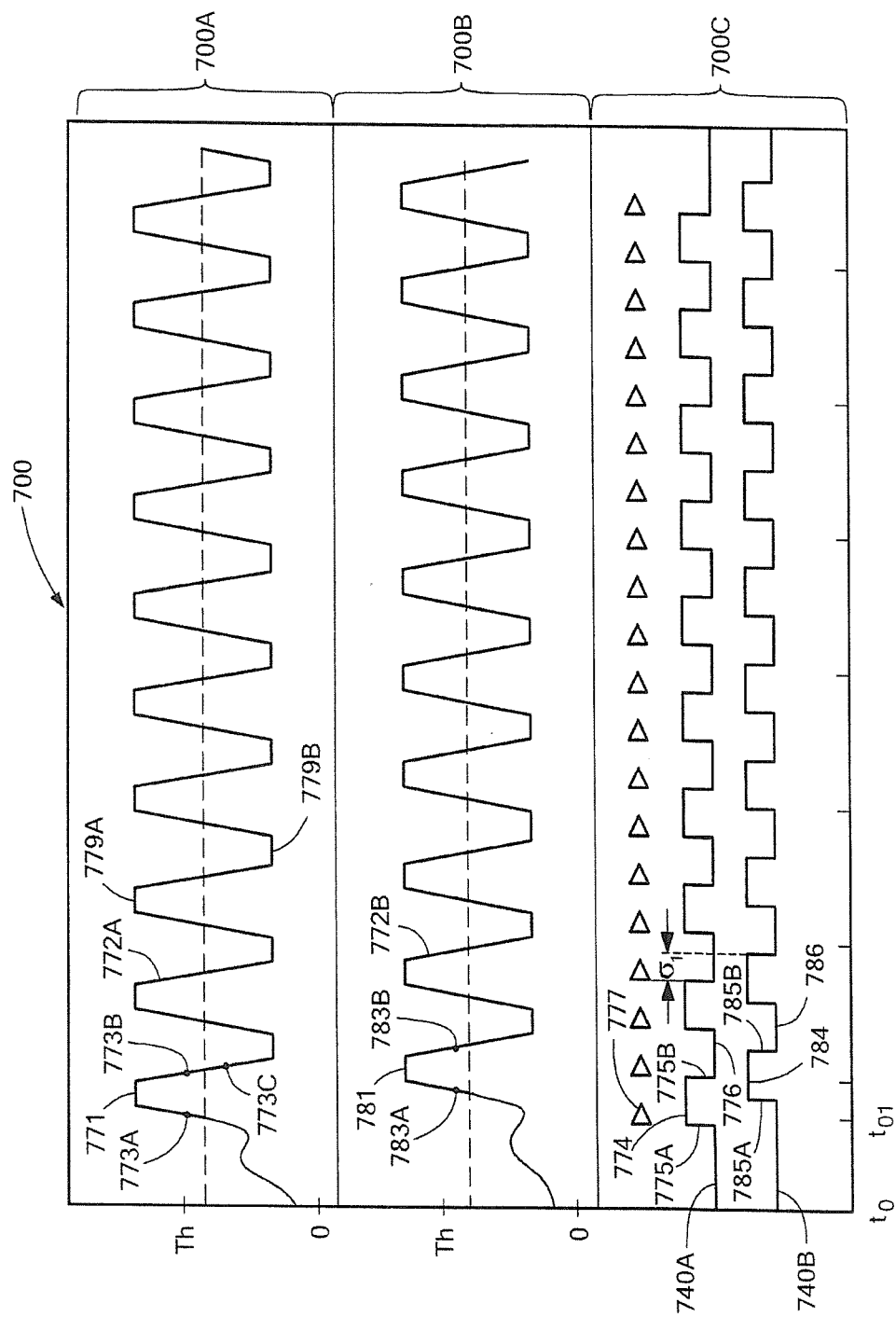


FIG. 7

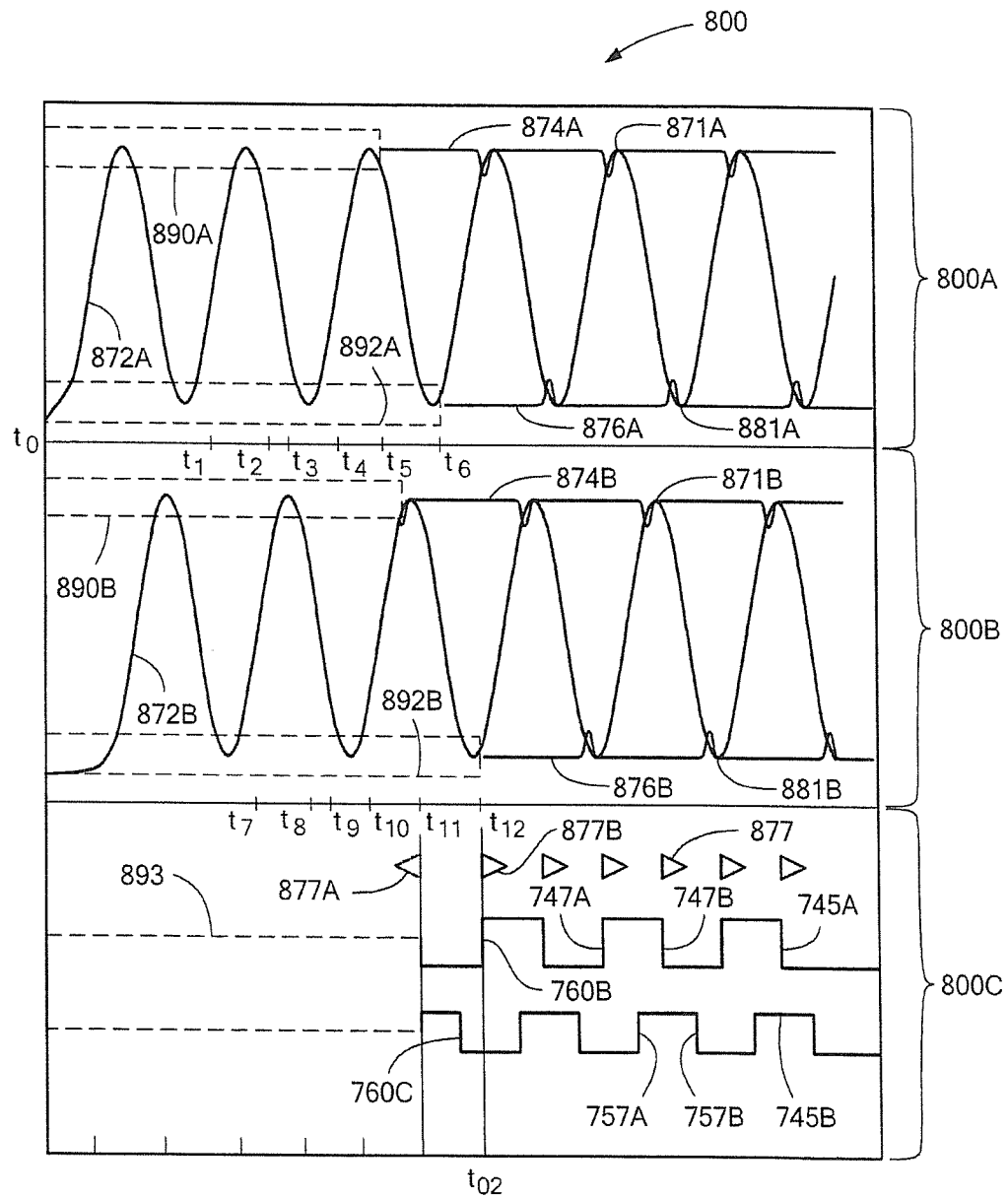
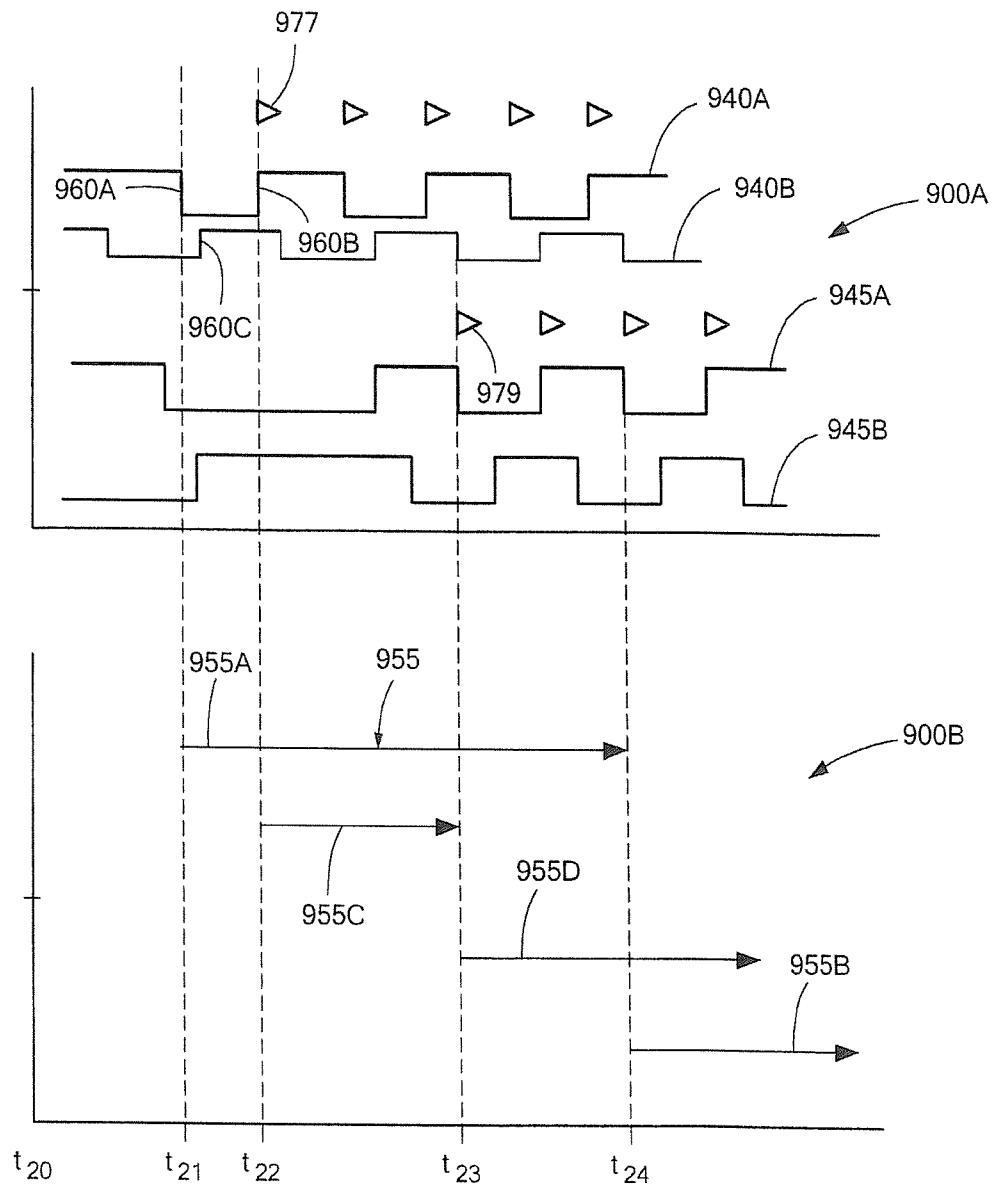


FIG. 8

**FIG. 9**

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2012/024583

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01D5/244

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)

G01D

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)

EP0-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.
X	WO 99/42789 A1 (ANALOG DEVICES INC [US]) 26 August 1999 (1999-08-26) page 19, line 2 - line 23; figure 1 -----	1-29
A	US 7 138 793 B1 (BAILEY JAMES M [US]) 21 November 2006 (2006-11-21) figure 1 -----	5,11,16, 23
A	DE 31 15 237 A1 (BOSCH GMBH ROBERT [DE]) 4 November 1982 (1982-11-04) abstract -----	18

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

☒ See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

27 April 2012

Date of mailing of the international search report

09/05/2012

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

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2012/024583

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9942789	A1	26-08-1999	DE 69910741 D1 02-10-2003
			DE 69910741 T2 17-06-2004
			EP 1060361 A1 20-12-2000
			JP 2002504672 A 12-02-2002
			US 6064199 A 16-05-2000
			WO 9942789 A1 26-08-1999

US 7138793	B1	21-11-2006	EP 2008064 A1 31-12-2008
			JP 2009533694 A 17-09-2009
			KR 20090007593 A 19-01-2009
			US 7138793 B1 21-11-2006
			WO 2007120395 A1 25-10-2007

DE 3115237	A1	04-11-1982	DE 3115237 A1 04-11-1982
			JP 57181972 A 09-11-1982
