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- (54) **NORMALIZING CAPACITIVE SENSOR ARRAY SIGNALS**
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U.S. Appl. No. 13/156,297: "Normalizing Capacitive Sensor Array Signals" Ryan D. Seguine et al., filed Jun. 8, 2011; 48 pages.

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U.S. Applications:

- (63) Continuation of application No. 12/167,552, filed on Jul. 3, 2008, now Pat. No. 8,064,417.
- (60) Provisional application No. 60/947,903, filed on Jul. 3, 2007.

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- (52) **U.S. Cl.**
CPC **G01D 5/24** (2013.01)
- (58) **Field of Classification Search**
USPC 702/150
See application file for complete search history.

(57)

ABSTRACT

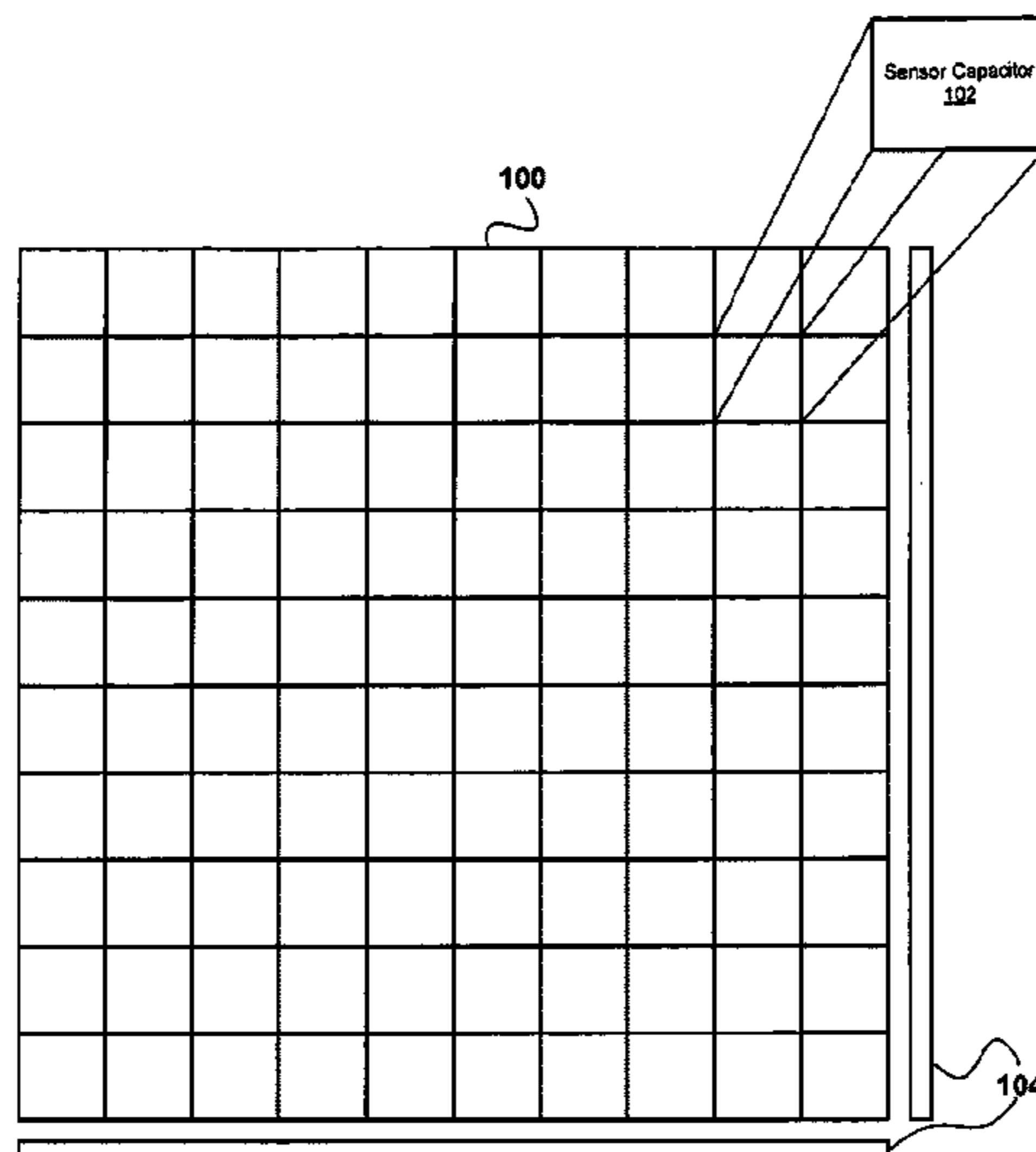
An embodiment of the present invention is directed to a method for reporting position information. Position information received from a plurality of capacitive sensors in an array of capacitive sensors is adjusted based on predetermined adjustment values to generate adjusted position information. Each predetermined adjustment value is associated with at least one of the plurality of capacitive sensors. A signal representative of the adjusted position information is generated. In another embodiment, the sensitivity of at least one of the capacitive sensors is adjusted based on the position of the at least one capacitive sensor within the array.

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19 Claims, 10 Drawing Sheets



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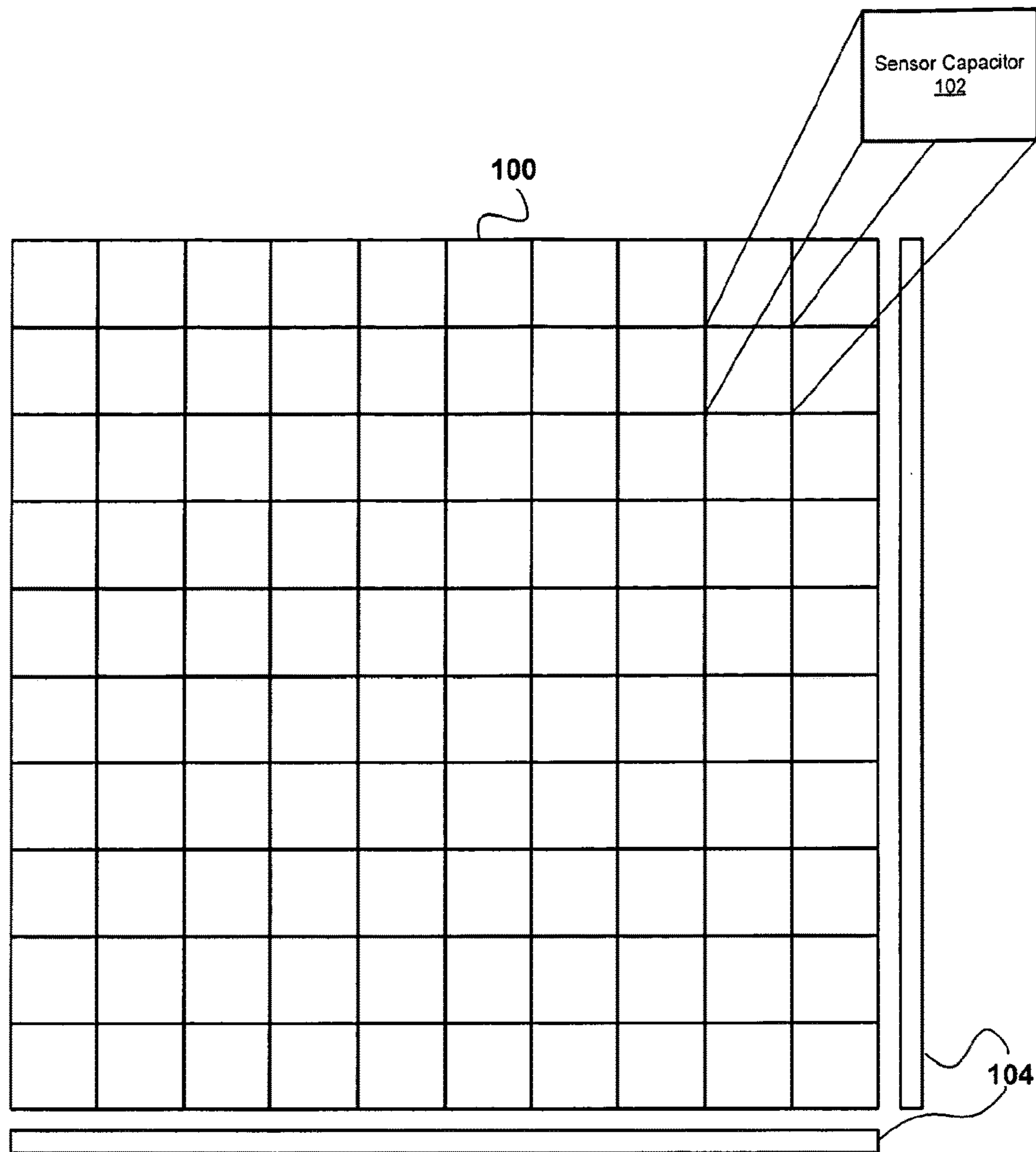


Fig. 1

200

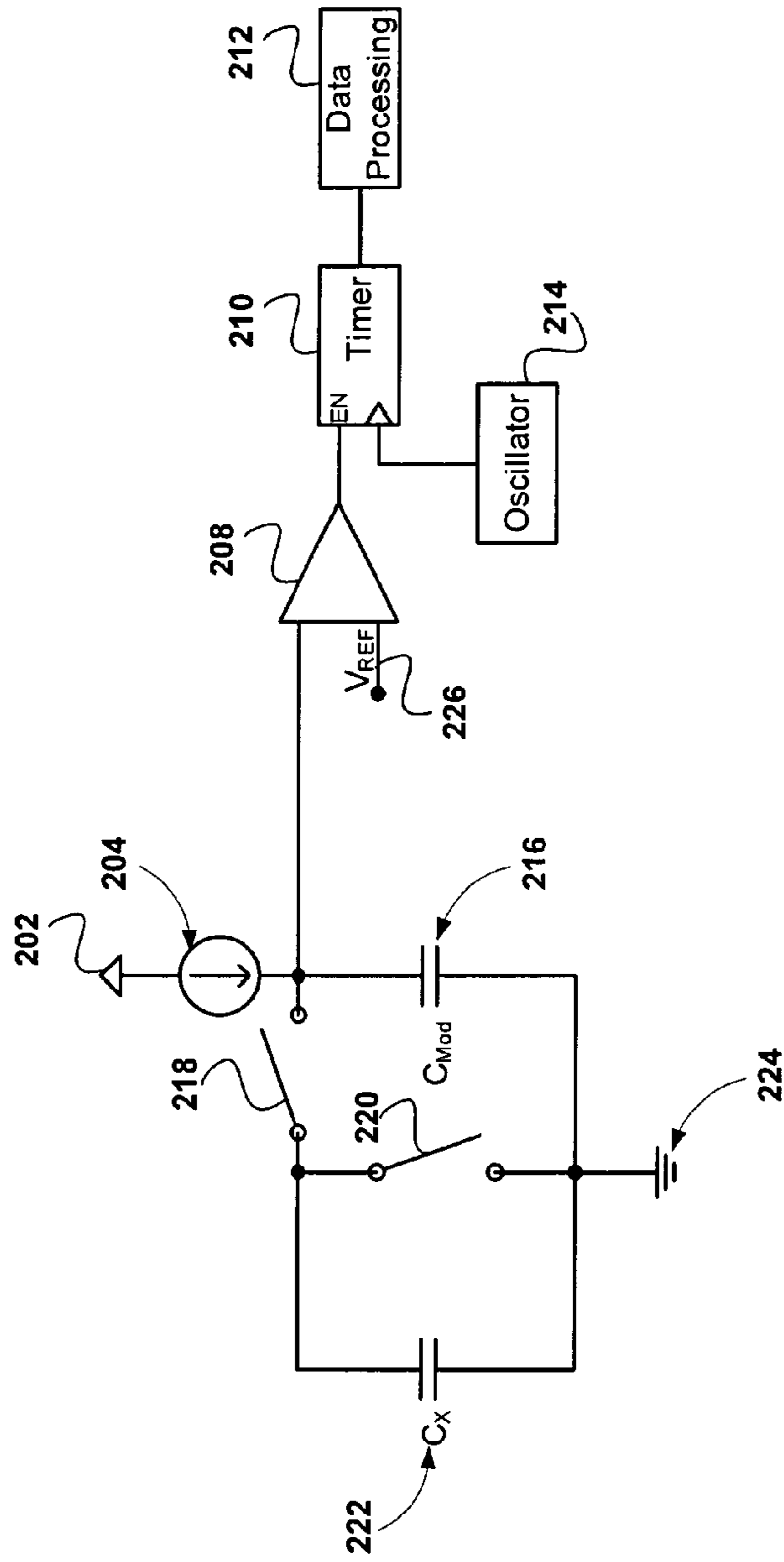


Fig. 2

300

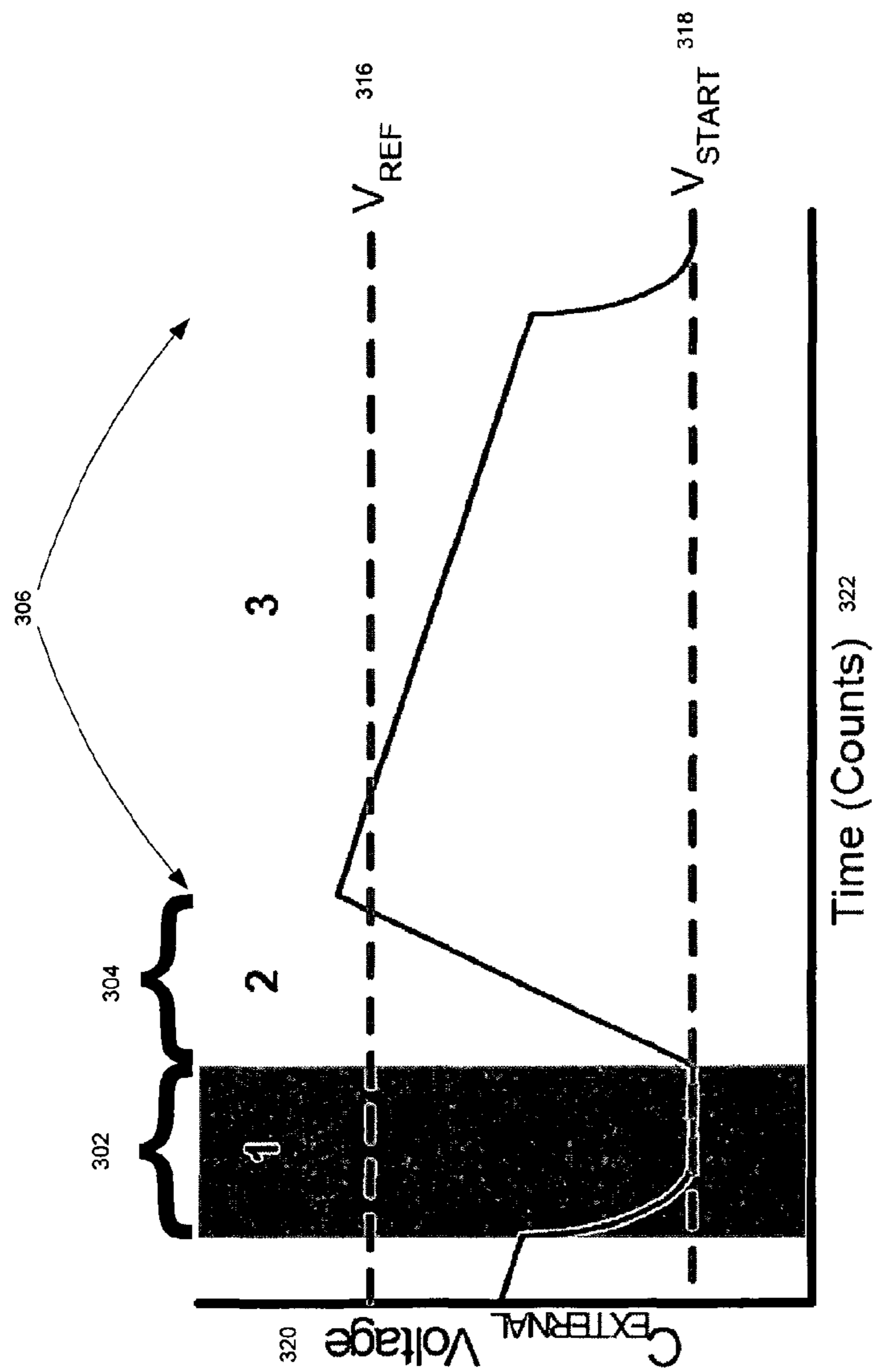


Fig. 3

400

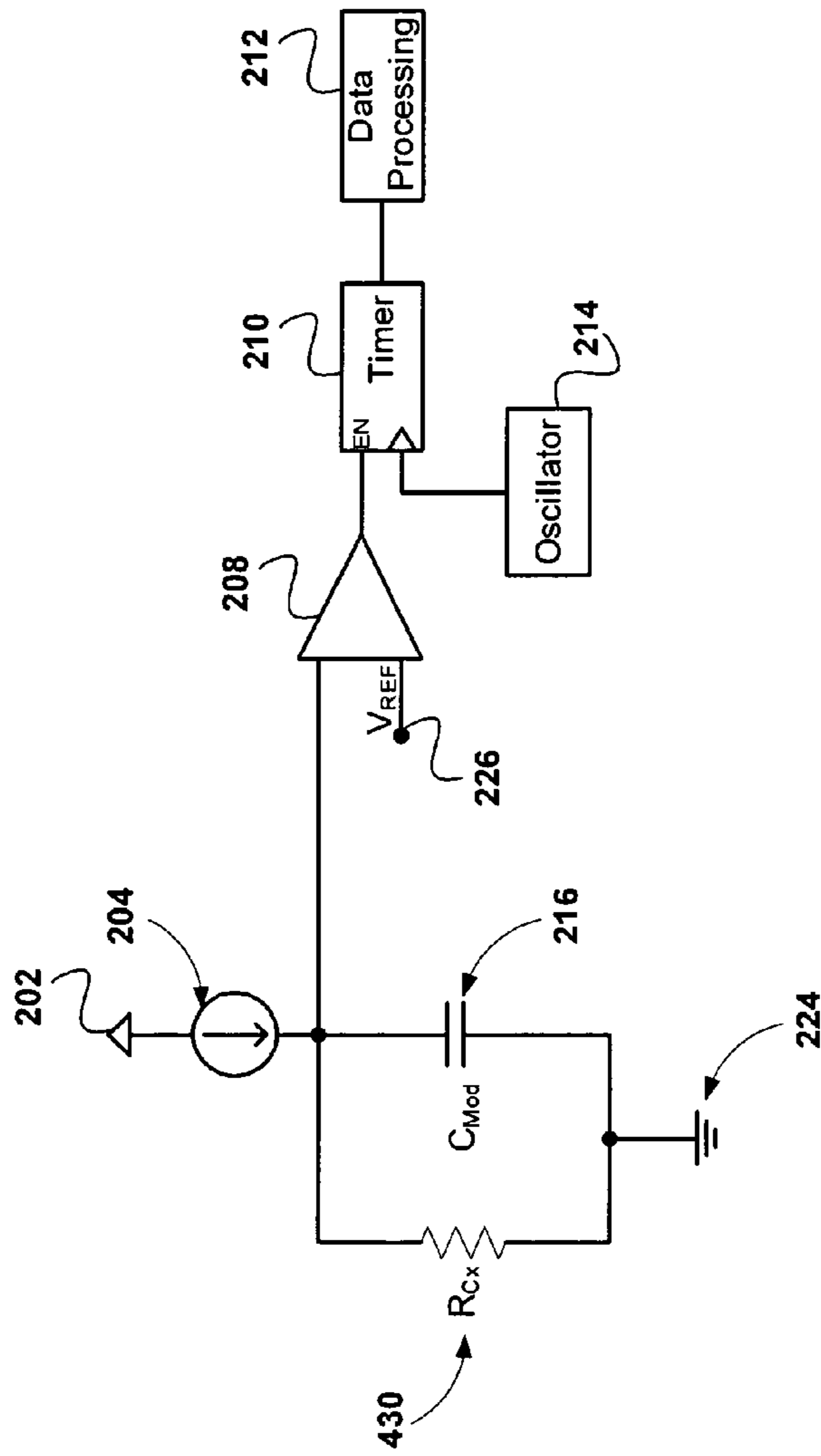


Fig. 4

500

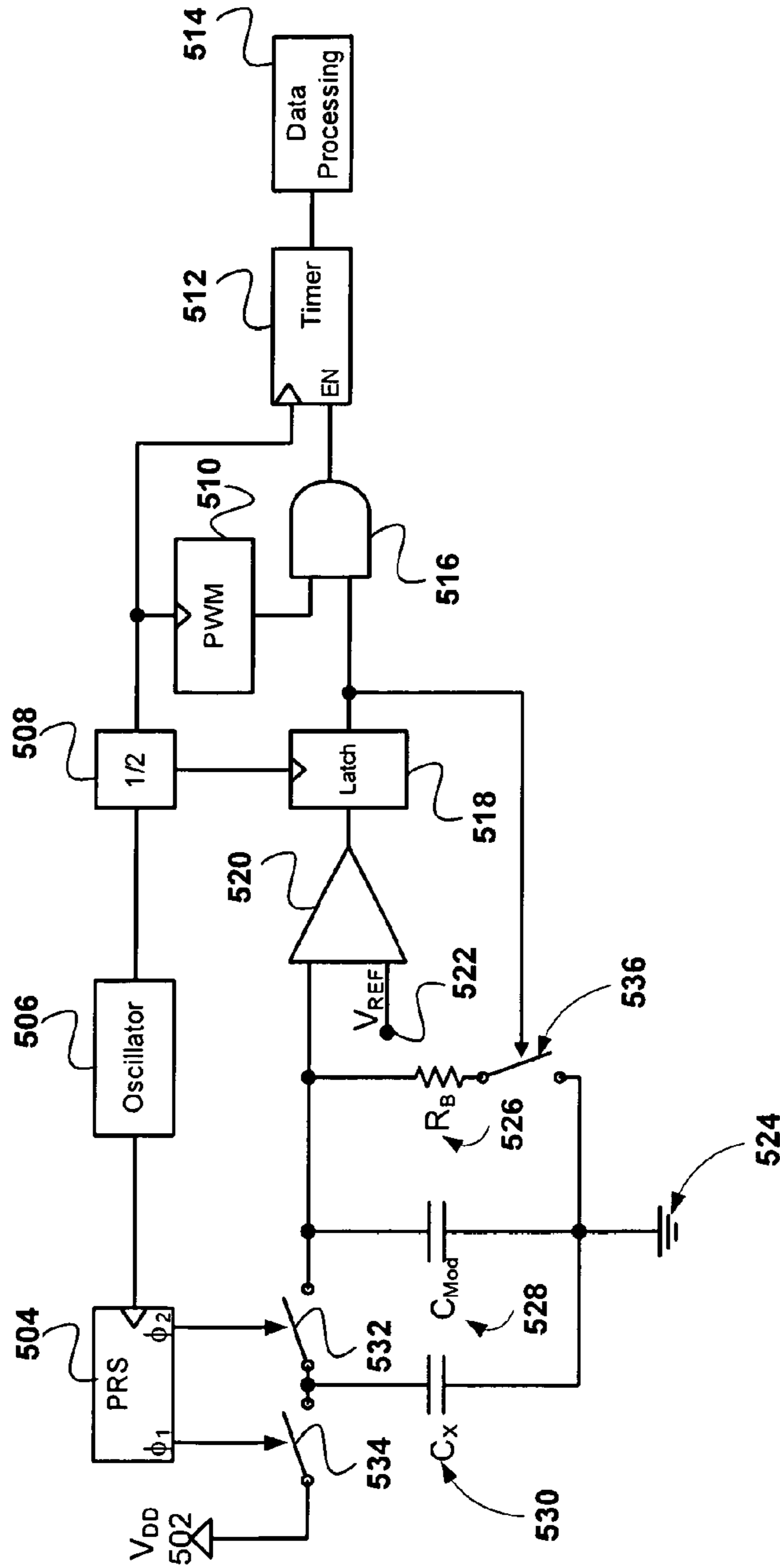


Fig. 5

600

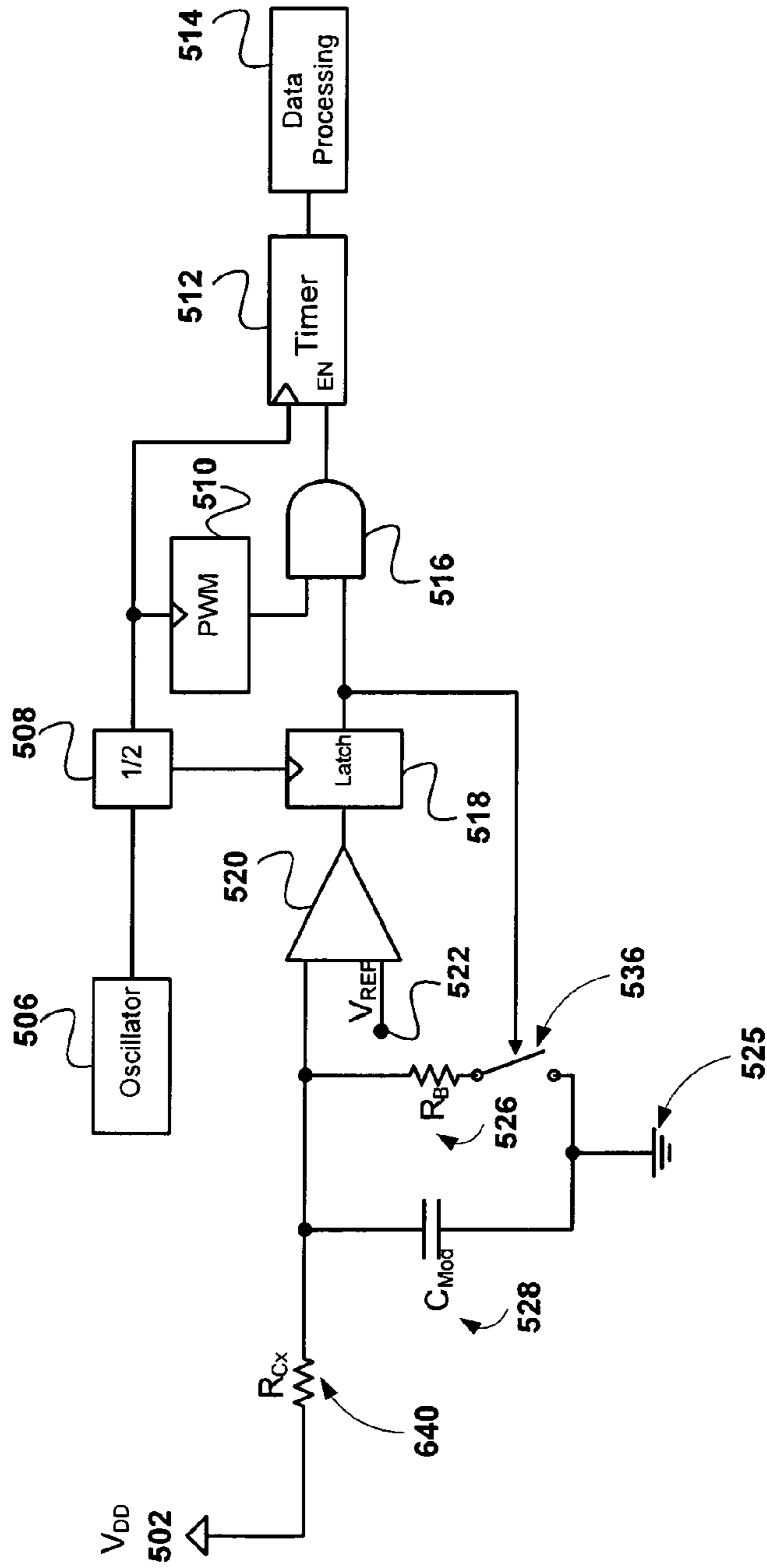


Fig. 6

700

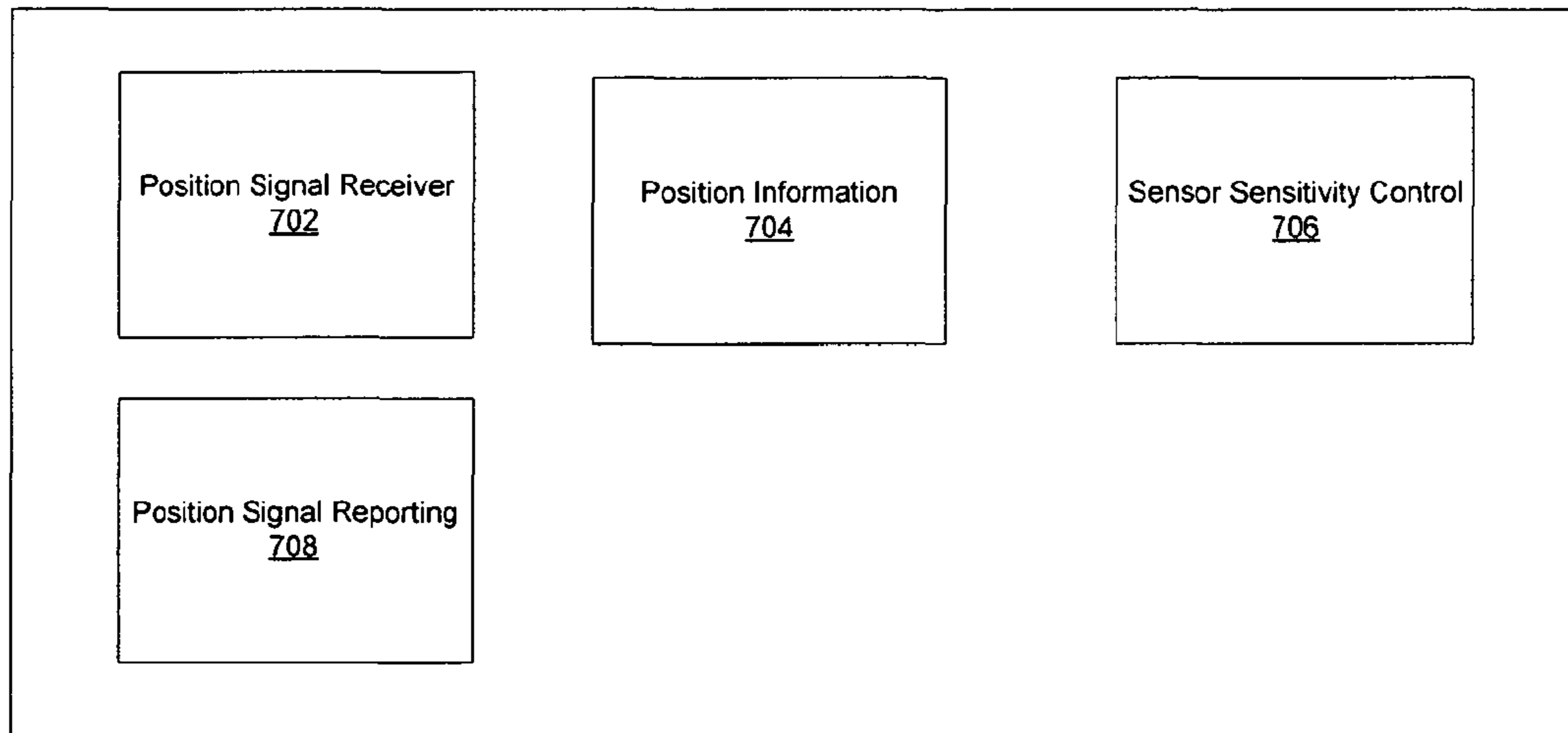


Fig. 7

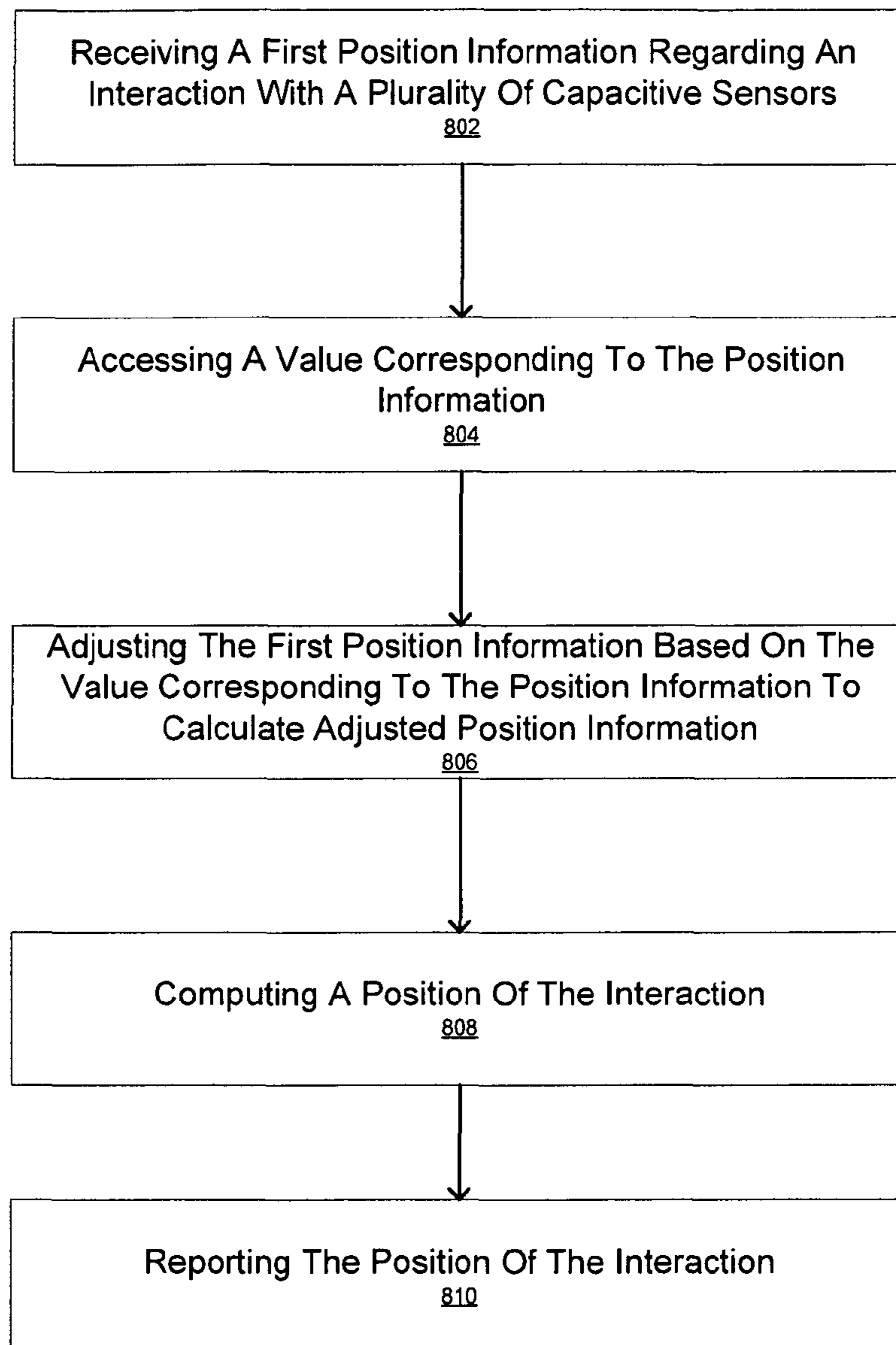
800

Fig. 8

900

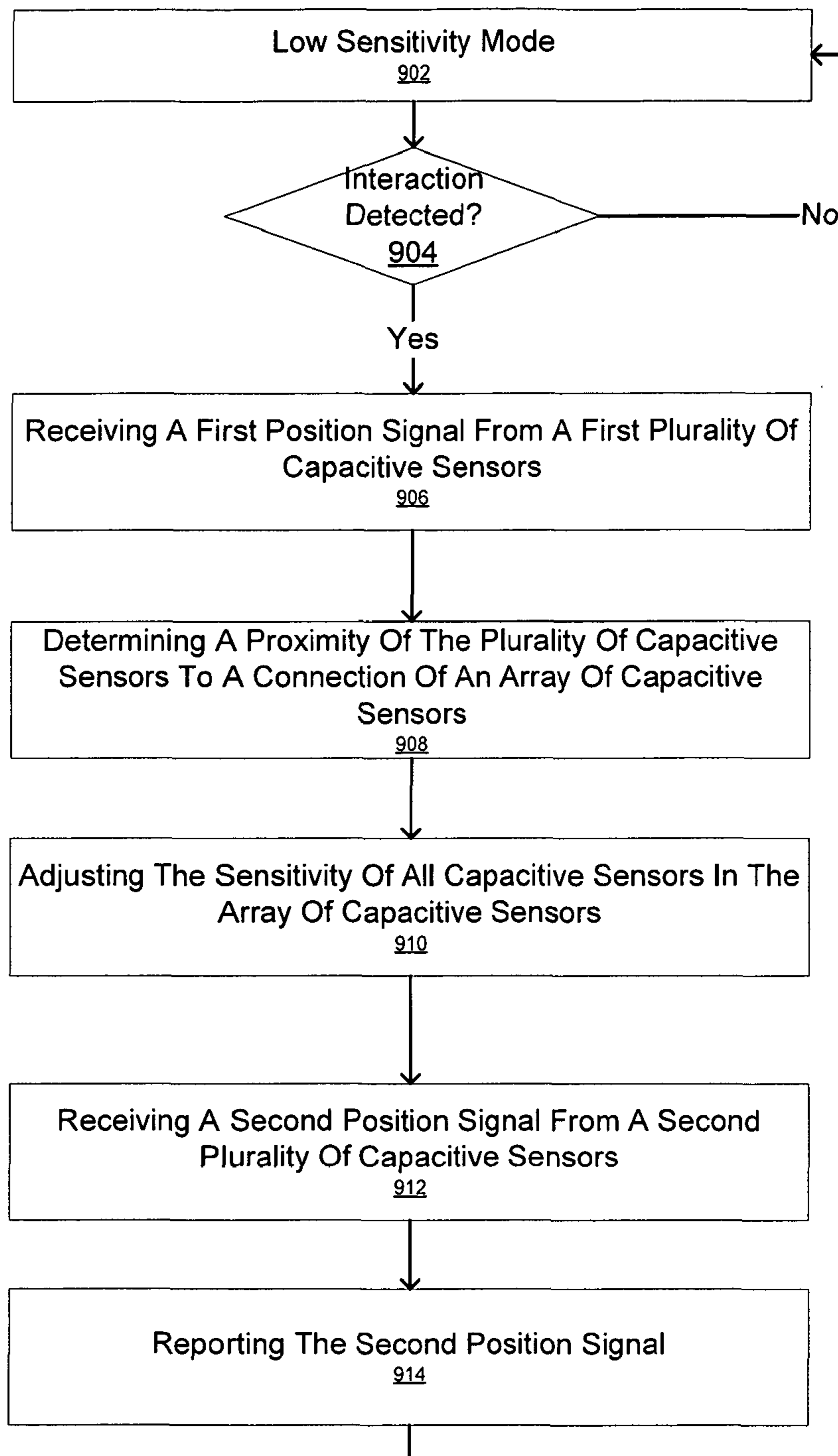


Fig. 9

1000

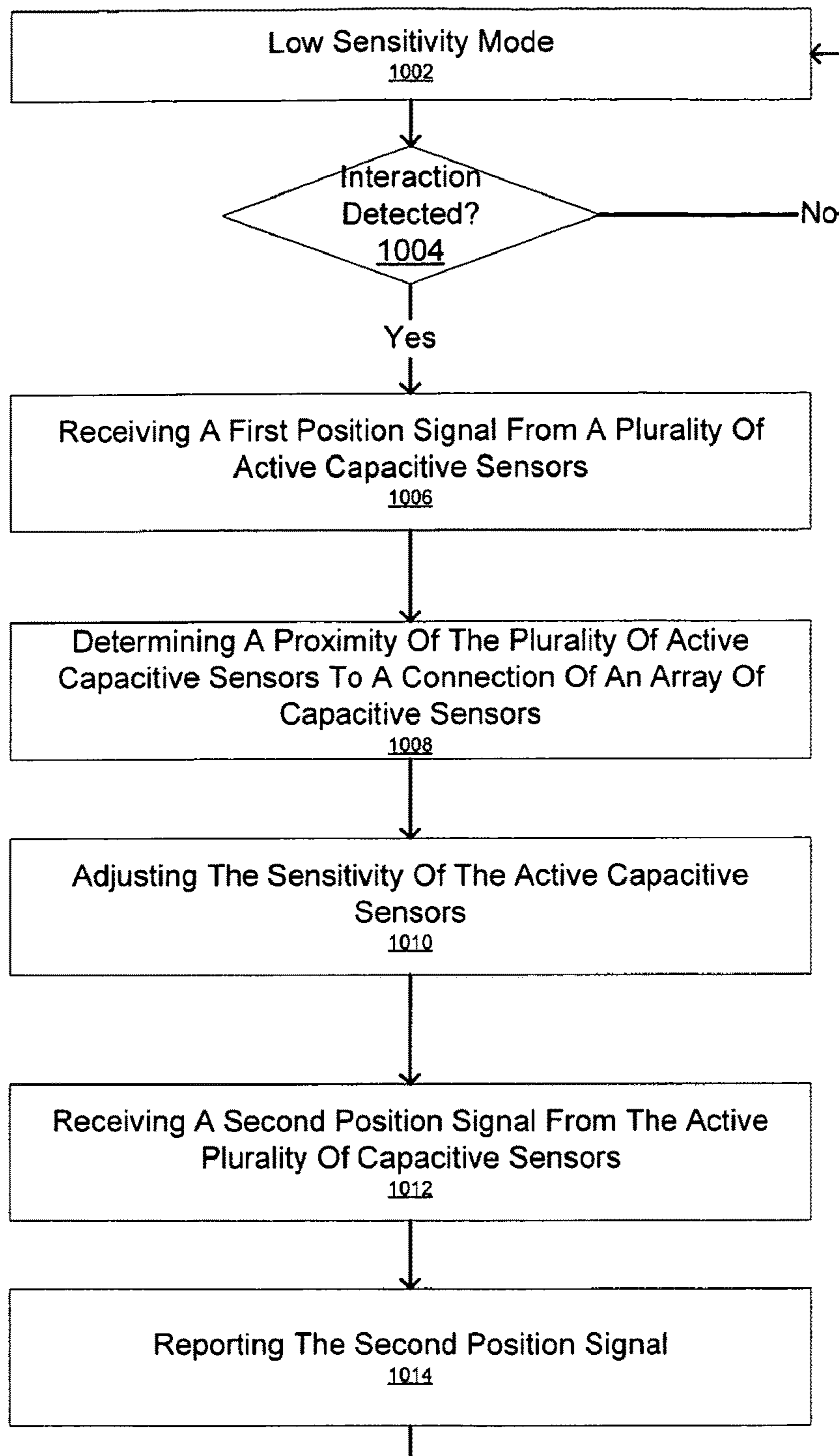


Fig. 10

NORMALIZING CAPACITIVE SENSOR ARRAY SIGNALS

Matter enclosed in heavy brackets [] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue; a claim printed with strikethrough indicates that the claim was canceled, disclaimed, or held invalid by a prior post-patent action or proceeding.

RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 12/167,552, filed Jul. 3, 2008, which claims the benefit of U.S. Provisional Application No. 60/947,903, filed on Jul. 3, 2007, both of which are incorporated herein by reference.

FIELD OF THE INVENTION

Embodiments of the present invention generally relate to capacitive sensor arrays.

BACKGROUND OF THE INVENTION

As computing technology has developed, user interface devices have advanced correspondingly. User interfaces have become increasingly significant in the usability of a computing device.

One particular user interface becoming increasingly popular is touch screen or track pad which uses an array of capacitive sensors using high impedance capacitance substrates. The sensor array is typically connected to detection logic via a portion of the sides of the array. The sensor array is divided up into rows and columns each with corresponding capacitive sensing elements. In order for a signal of a capacitive sensing element to be processed, the signal must travel through the rest of the row or column to be received by the detection logic. The greater the distance from the connection of the sensor array, the greater signal loss that occurs due to series impedance as the signal travels through the array to the detector logic. For example, for a sensor array having connections on the bottom and right, signals registered in the upper left corner will experience signal loss as the signals travel through the array connections. In contrast, signals registered at the bottom right of the array will have much less signal loss. The non-uniform signal loss characteristic may lead to inaccurate position determination across the face of the user interface panel. For an array of high impedance row and column sensors, the reduction in sensitivity occurs worse at the corner that is furthest away from the detection logic connection.

Thus, conventional user interface designs have signal loss issues as signals from sensors remote from the connection of a sensory array are impacted by the series impedance of the sensor array.

SUMMARY OF THE INVENTION

Accordingly, embodiments of the present invention are directed to a system and method for processing position signal information using high impedance capacitive sensors. The processing of the signal information overcomes the signal loss caused by series impedance of an array of capacitive sensors. Embodiments of the present invention

thus facilitate accurate reporting of position information from an array of capacitive sensors that utilize high impedance capacitive substrates.

More specifically, an embodiment of the present invention is directed to a method for processing a position signal. The method includes receiving a first position signal from a capacitive sensor and determining a proximity of the capacitive sensor to a connection of an array of capacitive sensors. The sensitivity of the capacitive sensor is then adjusted (e.g., by adjusting the scan time) and a second position signal (e.g., including a more sensitive sensor reading) is received from the capacitive sensor. The second position signal may then be reported.

Another embodiment of the present invention is directed to a system for processing position information using capacitive sensors. The system includes a position signal receiver for receiving a position signal from an array of capacitive sensors and a position information module for accessing information corresponding with the position signal. The information may include values to be applied to the position signal. The system further includes a sensor sensitivity control module for adjusting the sensitivity of a capacitive sensor (e.g., adjusting the scan time or applying a value corresponding to the location of a sensor) and a position signal reporting module for reporting the position signal to a coupled device (e.g., computing device).

Another embodiment of the present invention is a method for reporting position information using capacitive sensors. The method includes receiving position information from a capacitive sensor and accessing a value corresponding to the position information. The value accessed may correspond to the location of the capacitive sensor within an array of capacitive sensors. The method further includes adjusting the position information based on the value corresponding to the position information and reporting the adjusted position information.

Another embodiment of the present invention is a method for processing a position signal. The method includes receiving a first position signal from a plurality of active capacitive sensors and determining a proximity of the plurality of active capacitive sensors to a connection of an array of capacitive sensors. The method further includes adjusting the sensitivity of the active capacitive sensors and receiving a second position from the plurality of active capacitive sensors. The second position signal (e.g., more sensitive signal) may then be reported.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure is illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings.

FIG. 1 shows block diagram of an exemplary capacitive sensor array, in accordance with one embodiment of the present invention

FIG. 2 shows an exemplary sensor circuit, in accordance with one embodiment of the present invention.

FIG. 3 shows an exemplary timing diagram or voltage graph of a capacitor of the exemplary sensor circuit of FIG. 2, in accordance with an embodiment of the present invention.

FIG. 4 shows the exemplary sensor circuit of FIG. 2 with an equivalent resistance during phase 1, in accordance with an embodiment of the present invention.

FIG. 5 shows another exemplary sensor circuit, in accordance with another embodiment of the present invention.

FIG. 6 shows the exemplary sensor circuit of FIG. 5 with an equivalent resistance, in accordance with an embodiment of the present invention.

FIG. 7 shows a block diagram of a system for processing position information, in accordance with another embodiment of the present invention.

FIG. 8 shows a flowchart of an exemplary process for reporting position information, in accordance with an embodiment of the present invention.

FIG. 9 shows a flowchart of an exemplary process for processing a position signal, in accordance with an embodiment of the present invention.

FIG. 10 shows a flowchart of an exemplary process for processing a position signal, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

Reference will now be made in detail to the preferred embodiments of the claimed subject matter, examples of which are illustrated in the accompanying drawings. While the invention will be described in conjunction with the preferred embodiments, it will be understood that they are not intended to limit the claimed subject matter to these embodiments. On the contrary, the claimed subject matter is intended to cover alternatives, modifications and equivalents, which may be included within the spirit and scope of the claimed subject matter as defined by the claims. Furthermore, in the detailed description of the present invention, numerous specific details are set forth in order to provide a thorough understanding of the claimed subject matter. However, it will be obvious to one of ordinary skill in the art that the claimed subject matter may be practiced without these specific details. In other instances, well known methods, procedures, components, and circuits have not been described in detail as not to unnecessarily obscure aspects of the claimed subject matter.

FIG. 1 shows block diagram of an exemplary capacitive sensor array, in accordance with one embodiment of the present invention. Capacitive sensor array 100 may provide a user interface (e.g., touchpad, track pad, touch screen, and the like) for a variety of devices including, but not limited to, servers, desktop computers, laptops, tablet PCs, mobile devices, music devices, video devices, cellular telephones, and smartphones etc. Capacitive sensor array 100 may include a plurality of sensor elements in a row and column configuration that utilize a high impedance capacitance substrate. Another possible structure for a capacitive sensing array is described in US Patent Application Publication No. 2007/0229470.

Sensor capacitor 102 illustrates an exemplary capacitive sensor cell in capacitive sensor array 100. Capacitive sensor array 100 may be configured in a variety of ways including, but not limited to, a square, a rectangle, a circle, or a ring etc. Connections 104 facilitate coupling of capacitive sensor array 100 to detection logic for detecting and reporting a user contact and its position to a coupled device (e.g., computing device).

In one embodiment, capacitive sensor array 100 is made of a material having an impedance which impacts signals received from sensor circuits remote from connections 104. For example, signals from sensor circuits in the upper left of capacitive sensor array 100 may be reduced or impacted by series impedance as the signal travels through the array to connections 104. It is appreciated that as the distance between connections 104 and a sensor of capacitive sensor circuit array 100 increases, the impact of the series imped-

ance of capacitive sensor array 100 increases. Embodiments of the present invention address this decrease in sensitivity to provide a more accurate position determination.

Example Circuits

FIGS. 2 and 4-6 illustrate example components used by various embodiments of the present invention. Although specific components are disclosed in circuits 200, 400, 500, and 600 it should be appreciated that such components are examples. That is, embodiments of the present invention are well suited to having various other components or variations of the components recited in systems 200, 400, 500, and 600. It is appreciated that the components in systems 200, 400, 500, and 600 may operate with other components than those presented, and that not all of the components of systems 200, 400, 500, and 600 may be required to achieve the goals of systems 200, 400, 500, and 600.

FIG. 2 shows an exemplary sensor circuit 200, in accordance with one embodiment of the present invention. Sensor circuit 200 includes Vdd signal 202, current source 204, comparator 208, timer 210, data processing module 212, oscillator 214, reference voltage 226, external modification capacitor 216, ground signal 224, sensor capacitor 222 (located in the sensor array), switch 220 and switch 218. Current source 204 may be a current DAC (Digital to Analog converter). Circuits of the type shown in FIG. 2 are described in more detail in U.S. Pat. Nos. 7,307,485 and 7,375,535.

In one embodiment, circuit 200 may operate in three phases. In a first phase (See 302, FIG. 3), switch 218 alternatively couples current source 204 to sensor capacitor 222 and current source 204 charges or settles external modification capacitor 216 to a start voltage, Vstart. In one embodiment, the start voltage may be governed the voltage current function expressed by:

$$V_{Start} = \frac{1}{f \cdot C_x} \cdot iDAC$$

Where f is the frequency of the switching of switch 218, Cx is the capacitance of the sensor capacitor 222, and iDAC is the current of current source 204.

It is appreciated that the capacitance of sensor capacitor 222 (one of the capacitors of array 100 of FIG. 1) varies with the presence of objects (e.g., a finger). For example, the presence of a finger may increase the capacitance and thereby result in a lower starting voltage. Conversely, a higher starting voltage may result from no finger being present.

In a second phase (See 304, FIG. 3), the sensor capacitor 222 is decoupled from current source 204 by switch 218 and sensor capacitor 222 is discharged by coupling to ground signal 224 via switch 220. External modification capacitor 216 may be charged by current source 204 until the voltage across it increases to reference voltage 226 at which time comparator 208 is tripped which disables timer 210. In one embodiment, voltage on the external modification capacitor 216 is reduced through a low pass filter in series with external modification capacitor 216 to the input of comparator 208.

In one embodiment, timer 210 is a counter (e.g., 16-bit). The raw number of counts on timer 210 measures the time required from Vstart to Vref (reference voltage 226) and may be used to determine if a finger is present on sensor capacitor 222. The raw counts are taken after each measurement sequence (e.g., after each charge of sensor capacitor

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222 and tripping of comparator 208) and then compared to a stored baseline number of counts with no finger present on sensor capacitor 222. If the difference between the raw counts and the baseline counts exceeds a threshold, then sensor activation is detected for that sensor. The value of the counter may measure how long it took for the voltage across external modification capacitor 216 to reach the threshold or reference voltage 226 and can then be used to determine what the start voltage was which is a measure of whether or not a finger was present.

For example, when no finger is present, 100 cycles may be required to bring the voltage across external modification capacitor 216 to reference voltage 226. When a finger is present, 105 cycles may be required to bring the voltage across external modification capacitor 216 to reference voltage 226. If there is a threshold of three cycles to indicate the presence of an object, as long as the number of the change in cycles is greater than three, the sensor may be determined or considered to be active. It is appreciated that a difference threshold larger than zero prevents noise or other interference from appearing as an active sensor.

The time (or count) measured by timer 210 may be used by data processing module 212 to the detection logic to process the data and make decisions based on the capacitive inputs (e.g., sensors triggered by presence of a finger). Lower starting voltages (e.g., when a finger is present) lead to longer charge times as the current from the current source 204 flows into the external modification capacitor 216 and increases the voltage at the same rate. If the start voltage is low, the time or count measured by timer 210 will be relatively large because current source 204 will have to provide more charge to external modification capacitor 216 to reach reference voltage 226. If the start voltage is relatively high (e.g., no finger present), the time or count measured by time 210 is low as current source 204 provides less current to external modification capacitor 216 to reach reference voltage 226.

In a third phase (See 306, FIG. 3), the sensor scan is completed and current source 204 is turned off. During the third phase, the time or count from timer 210 may be processed and stored. Voltage on the external modification capacitor 216 decreases as charge dissipates by leakage currents until the next scan begins. In one embodiment, the amount of time that the voltage decreases is strictly dependent upon the firmware between each scan and the CPU (Central Processing Unit) clock speed. It is appreciated that the next scan may then start with the first phase on the same sensor circuit or another sensor circuit (e.g., an adjacent or active sensor circuit).

In another embodiment, comparator 208 may be replaced with an analog-to-digital converter (ADC). Charge from the sensor capacitor 222 is transferred to external modification capacitor 216 acting as a filter capacitor for a prescribed number of cycles. After the prescribed number of cycles is complete, the voltage on external modification capacitor 216 is measured by the ADC and the output of the ADC is proportional to the size of sensor capacitor 222. The measured value of the ADC may then be used to determine the presence of an object.

FIG. 3 shows an exemplary voltage graph of the exemplary sensor circuit of FIG. 2 in operation, in accordance with an embodiment of the present invention. Graph 300 includes vertical axis 320 corresponding to the voltage of external modification capacitor 216 and horizontal axis 322 corresponding to the time (or counts) which may be measured by timer 210. Graph 300 further includes voltage

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markers 316 corresponding to reference voltage 226 and voltage marker 318 corresponding to the start voltage.

As mentioned above, circuit 200 may operate in three phases. Graph 300 illustrates phase 1 with region 302 during which the voltage on external modification capacitor 216 is settled or brought to a start voltage.

Graph 300 illustrates phase 2 with region 304 during which external modification capacitor 216 is charged via current source 204 to reference voltage 226. The amount of time needed to reach reference voltage 226 is used by data processing module 212 to determine whether an object (e.g., finger) is present. It is appreciated that the voltage of external modification capacitor 216 may exceed reference voltage 226 before comparator 208 trips timer 210. To increase the sensitivity of this detection mechanism, the duration of 304 can be increased which will increase the resolution of the reading.

Graph 300 further illustrates phase 3 with region 306 during which external modification capacitor 216 is discharged. It is appreciated that external modification capacitor 216 may be discharged while other capacitive sensors of a capacitive sensor array are scanned.

FIG. 4 shows an exemplary sensor circuit with an equivalent resistance, in accordance with phase 1 of the circuit of FIG. 2. Sensor circuit 400 includes Vdd signal 202, current source 204, comparator 208, timer 210, data processing 212, oscillator 214, reference voltage 226, external modification capacitor 216, ground signal 224, sensor capacitor 222, and equivalent resistance 430.

In the first phase, a current value for current source 204 may be determined which results in a start voltage across equivalent resistance 430 that is below reference voltage 226.

The equivalent resistance 430 may be governed the voltage current function expressed by:

$$R_{Equivalent} = \frac{1}{f_s \cdot C_x}$$

Where f_s is the switching frequency of phases 1 and 2 as described herein, and C_x is the capacitance of sensor capacitor 22.

As shown, equivalent resistance 430 is inversely proportional to the capacitance of sensor capacitor 222. The presence of an object (e.g., finger) on a sensor therefore increases the capacitance of the sensor, which decreases equivalent resistance 430 formed by the switching phases 1 and 2. A decreased equivalent resistance results in a lower starting voltage by $V=IR$. In one embodiment, the start voltage may be governed the voltage current function expressed by:

$$V_{Start} = \frac{1}{f_s \cdot C_x} \cdot iDAC$$

Where f_s is the switching frequency of phases 1 and 2 as described herein, and C_x is the capacitance of sensor capacitor 222 and $iDAC$ is current of current source 204.

A lower starting voltage corresponds to an increased time for current source 204 to charge up external modification capacitor 216, thereby resulting in a larger time that timer 210 will operate. Data processing module 212 may thus

process the increased value from timer 210 to indicate the presence of an object relative to the equivalent resistance 430.

FIG. 5 shows an exemplary sensor circuit, in accordance with another embodiment of the present invention. Sensor circuit 500 includes Vdd 502, pseudo random generator 504, oscillator 506, frequency modifier 508, pulse-width modulator 510, counter 512, data processing module 514, and gate 516, latch 518, comparator 520, reference voltage 522, discharge resistor 526, ground signal 524, external modification capacitor 528, sensor capacitor 530, switch 532, switch 534, and switch 536.

Switches 532 and 534 are controlled by pseudo random generator 504, which modulates the voltage across external modification capacitor 528 about reference voltage 522 in charge up and charge down steps. Pseudo random generator 504 reduces the electromagnetic inference susceptibility and radiated emissions of capacitive sensing circuits. In one embodiment, external modification capacitor 528 is larger than sensor capacitor 530.

In one embodiment, switch 534 is used to charge sensor capacitor 530. The capacitance of sensor capacitor 530 varies with the presence of an object (e.g., a finger). After the charging of sensor capacitor 530, switch 534 is decoupled and switch 532 is coupled thereby allowing the charge of sensor capacitor 530 to flow to external modification capacitor 528.

As the charge in external modification capacitor 528 increases, so does the voltage across external modification capacitor 528. The voltage across external modification capacitor 528 may be an input to comparator 520. When the input to comparator 520 reaches the threshold voltage or reference voltage 522, discharge resistor 526 is connected and charge is bled off of external modification capacitor 528 at a rate determined by the starting voltage across the external modification capacitor 528 and the value of discharge resistor 526. As the voltage across external modification capacitor 528 decreases and the voltage passes reference voltage 522, discharge resistor 526 is disconnected from ground 524 via switch 536.

The charge/discharge cycle of the external modification capacitor 528 is manifested as a bit stream on the output of comparator 520. The bit-stream of comparator 520 is 'ANDed' with pulse-width modulator 510 via and gate 516 to enable timer 512. Pulse width modulator 510 sets the time-frame or measurement window in which the bit-stream enables and disables timer 512. The capacitance measurement and therefore the presence of an object is a matter of comparing the bit-stream of the comparator to the known, baseline value.

The value of reference voltage 522 affects the baseline level of counts or time measured by timer 512 from a sensor when no finger is on the sensor. This voltage on an external modification capacitor 528 may reach the reference voltage before comparator 520 trips, so the value of reference voltage 522 affects the amount of time that it takes external modification capacitor 528 to charge to reference voltage 522, decreasing the density of the bit-stream during a scan.

The output of timer 512 is used for processing the level of capacitance change and determining the sensor activation state. The duration of these steps is compared relative to each other by looking at the comparator bit-stream density. If the density of the bit-stream is relatively high, the sensor is read as "on". The bit-stream output of comparator 520 is synchronized with system clock via latch 518.

FIG. 6 shows an equivalent resistance of the circuit of FIG. 5, in accordance with an embodiment of the present

invention. Sensor circuit 600 includes Vdd 502, oscillator 506, frequency modifier 508, pulse-width modulator 510, counter 512, data processing module 514, and gate 516, latch 518, comparator 520, reference voltage 522, discharge resistor 526, ground signal 524, external modification capacitor 528, switch 536, and equivalent resistance 640.

Sensor capacitor 530 is replaced with equivalent resistance 640. Equivalent resistance 640 is inversely proportional to the capacitance of sensor capacitor 530. As such, the presence of an object (e.g., a finger) will result in an increase in capacitance and a corresponding reduction in the resistance of equivalent resistance 640. The reduction of equivalent resistance 640 thereby allows more current to charge external modification capacitor 528 and thereby allowing the voltage across external modification capacitor 528 to reach reference voltage 522 relatively faster.

Example System

FIG. 7 illustrates example components used by various embodiments of the present invention. Although specific components are disclosed in system 700 it should be appreciated that such components are examples. That is, embodiments of the present invention are well suited to having various other components or variations of the components recited in system 700. It is appreciated that the components in system 700 may operate with other components than those presented, and that not all of the components of system 700 may be required to achieve the goals of system 700.

FIG. 7 shows a block diagram of a system for processing position information, in accordance with another embodiment of the present invention. System 700 may be coupled to an array of capacitive sensors comprising a plurality of sensor circuits as described herein.

Position signal receiver 702 receives position signals from an array of capacitive sensors. As described herein, the position signals may be received from one or more sensor circuits of an array of capacitive sensors. The position signals may further originate from multiple sensors comprising a centroid.

Position information module 704 accesses information corresponding with the position signal received by position signal receiver 702. The information may correspond with the position signal and include location information of a capacitive sensor within the array of capacitive sensors. For example, information regarding the relative location of a capacitive sensor relative to a connection (e.g., connections 104) of an array of capacitive sensors may be accessed. It is appreciated that values may be accessed as new position information is received from active sensors (e.g., as an object moves around).

The information may further include a scalar value for adjusting a position signal. The scalar value may be dependent on the sensor's distance from the detection logic and therefore based on the sensor's location within the array. In one embodiment, the value may be based on the percentage of reduction of the signal impacted by the impedance of the array as the signal is transmitted to a connection of a capacitive sensor array. For example, the scalar value may be used to increase a signal level by 50% of a capacitive sensor in the top left of a capacitive sensor in the array where the connections are in the bottom right. The scalar value may be based on the capacitive sensor's location resulting in a 50% reduction in the signal received at the connections of the array. It is appreciated that a scalar value corresponding to sensors adjacent to the connections of an array of capacitive sensors may not need to be applied.

In one embodiment, the scalar values may be stored in a matrix with each sensor circuit having a corresponding

scalar value. For example, scalar values for adjusting position signals from sensor circuits remote from the connection of the array of capacitive sensors may be greater than the scalar values for sensor circuits near or adjacent to the connections of the array of capacitive sensors.

Scalar values corresponding to each sensor circuit may further facilitate more accurate readings from the array of capacitive sensors. For example, due to the impact of impedance on an array of capacitive sensors, centroid readings may be pulled down and to the right because the reading from sensors up and to the left are increasingly impacted by the series impedance of the array of capacitive sensors thereby having decreased sensitivity. The adjusting of centroid with the scalar values allows the centroid to be adjusted to compensate for the impact of the capacitance and thereby the centroid can be more accurately reported.

In another embodiment, all the sensor values may be adjusted by the same scalar value. For example, a scalar value may be multiplied or applied to each signal of each capacitive sensor in an array of capacitive sensors.

Sensor sensitivity control module **706** adjusts the sensitivity of one or more capacitive sensors. The sensor sensitivity control module **706** may adjust the sensitivity of one or more active capacitive sensors or a plurality of the capacitive sensors (e.g., including active and inactive sensors) in an array of capacitive sensors.

Sensor sensitivity control module **706** adjusts the sensitivity of one or more capacitive sensors by adjusting a scan time of the one or more capacitive sensors. The adjustment of the scan time of the capacitive sensors facilitates greater resolution and signal levels in readings from the capacitive sensors. The sensitivity may be adjusted according to the proximity of the sensors to the connections of the array of capacitive sensors. In one embodiment, the adjustment of the scan time increases the resolution and signals levels by increasing the detection period (e.g., phase 2 of circuit **200**).

In one embodiment, a current source (e.g., current source **204**) or capacitor (e.g., external modification capacitor **216**) of a sensor circuit (e.g., circuit **200**) may be adjusted to increase scan time. The adjustment of the current or capacitor value may result in increased counts or time measured by timer **210**. For example, the current of a current source (e.g., current source **204**) may be reduced which thereby increases the time before the reference voltage is reached and thereby increases the scan time.

In another embodiment, a pulse width modulator (e.g., pulse width modulator **510**) may be adjusted to increase period of an output of a bit-stream of a circuit (e.g., circuit **500**). The increased period of the output of the bit-stream enables higher raw counts or times to be measured thereby increasing the resolution of the sensor.

Sensor sensitivity control module **706** may further adjust the sensitivity of one or more capacitive sensors based on information corresponding to a location within the array of capacitive sensors including, but not limited to, scalar values accessed via position information module **704**.

Position signal reporting module **708** reports the position signal. Position signal reporting module **708** may report a position signal after that has been adjusted by sensor sensitivity control module **706**. For example, a first position signal may be received and a second signal may be reported after the sensitivity of the corresponding sensor has been adjusted by sensor sensitivity control module **706**.

Example Operations

With reference to FIGS. **8-10**, exemplary flowcharts **800-1000** each illustrate example blocks used by various embodiments of the present invention. Although specific

blocks are disclosed in flowcharts **800-1000**, such blocks are examples. That is, embodiments are well suited to performing various other blocks or variations of the blocks recited in flowcharts **800-1000**. It is appreciated that the blocks in flowcharts **800-1000** may be performed in an order different than presented, and that not all of the blocks in flowcharts **800-1000** may be performed.

FIG. **8** shows a flowchart **800** of an exemplary process for reporting position information, in accordance with an embodiment of the present invention. The blocks of flowchart **800** may be performed by a data processing portion (e.g., data processing module **212** or data processing module **514**) of a sensor circuit (e.g., sensor circuits **200** and **400-600**).

At block **802**, first position information regarding an interaction is received from a number of capacitive sensors. As described herein, the position information may include a centroid computation and may be received from one or more capacitive sensors in an array of capacitive sensors. Sensors reporting a signal that exceeds a threshold are active and contribute to the centroid computation.

At block **804**, an adjustment value corresponding to the position information is accessed. As described herein, the adjustment value corresponding to the position information may be based on a location of the active capacitive sensor within an array of capacitive sensors relative to the connections of the array. For example, a larger adjustment value may correspond to sensors whose signal is impacted by the series impedance of the array of capacitive sensors as the signal travels to the connections of the array of capacitive sensors. In one embodiment, each capacitive sensor in the array may have a respective adjustment value assigned to it based on its relative distance to the detector logic. At step **804**, the adjustment values are obtained for the active sensors participating in the centroid computation.

At block **806**, the first position information is adjusted based on the adjustment values corresponding to the position information to calculate an adjusted position information. The adjusting may include multiplying the signals corresponding to the first position information with the adjustment values which may be scalar values. As described herein, the values may be applied to active sensors or one or more sensors of the array of capacitive sensors. It is appreciated that the adjustment of the position information may improve the signal level reported by sensor and thereby compensate for the impact of impedance on the array of capacitive sensors. In accordance with the embodiment described above, the sensor readings for the active sensors are multiplied by their respective adjustment values. This new data is then used to determine an adjusted position.

At block **808**, a position of the interaction is computed using the adjusted signals. In one embodiment, the centroid is again calculated based on the adjusted position information.

At block **810**, the position of the interaction as computed in **808** is reported. As described herein, the position of the interaction (e.g., centroid) may be reported to the device (e.g., computing device and the like) coupled to the array of capacitive sensors.

FIG. **9** shows a flowchart **900** of an exemplary process for processing a position signal, in accordance with another embodiment of the present invention. The blocks of flowchart **900** may be performed by a data processing portion (e.g., data processing module **212** or data processing module **514**) of a sensor circuit (e.g., sensor circuits **200** and **400-600**). It is appreciated that blocks or select blocks of

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flowchart **900** may be repeated as the position signal (e.g., centroid) moves around an array of capacitive sensors.

At block **902**, the array of capacitive sensors is in a low sensitivity mode with all sensors scanned. In one embodiment, the array of capacitive sensors may operate in a low sensitivity mode while no interactions with the array are detected.

At block **904**, whether an interaction with the array of capacitive sensors has occurred is detected. If there is no interaction detected, the capacitive sensor array remains in low sensitivity mode at block **902**. If an interaction is detected, the capacitive sensor array may proceed to block **906**.

At block **906**, a first position signal is received from a first plurality of capacitive sensors. As described herein, the first position signal may be computed from a centroid and may be received from a plurality of capacitive sensors which are part of an array of capacitive sensors.

At block **908**, a proximity of the plurality of capacitive sensors to a connection of an array of capacitive sensors is determined on an individual level. As described herein, the relative locations of one or more capacitive sensors to the connections of an array of capacitive sensors may be determined.

At block **910**, the sensitivity of all capacitive sensors in the array of capacitive sensors is adjusted. The sensitivity of one or more capacitive sensors may be adjusted to increase the resolution and signal level, thereby compensating for the impact of the impedance of an array of capacitive sensors. Adjusting the sensitivity of all of the sensors allows enhanced tracking of an object as movement is detected.

The sensitivity of the capacitive sensors may be adjusted by adjusting the scan time of the capacitive sensors based individually on their location within the array. As described herein, the scan time of an individual sensor circuit may be adjusted by adjusting the current (e.g., lowering the current) for charging a capacitor of a current source (e.g., current source **204**), adjusting a pulse width modulation (e.g., of pulse width modulator **410**), a voltage threshold (e.g., reference voltage **226** or **422**), or adjusting a capacitance of an integration capacitor (e.g., external modification capacitor **428**). In one embodiment, the adjustment of the scan time increases the resolution and signals levels by increasing the detection period (e.g., phase 2 of circuit **200**).

In one embodiment, the scan time may be adjusted according to the position of one or more capacitive sensors. For example, the scan time of sensors in the upper left could be increased more than the scan time in the middle of a capacitive sensor array where the connections of the array are in the lower right. In one embodiment, each sensor may have a respective adjustment factor that is based on its distance from the detecting logic.

At block **912**, a second position signal is received from a second plurality of capacitive sensors. The second position signal may be received after the sensitivity of the sensors has been adjusted as described herein. It is appreciated that the second plurality of sensors may be different from the first plurality of sensors where the object has moved before the sensitivity of the sensors has been adjusted. The first plurality of sensors and the second plurality of sensors may be same when the object has not moved. At block **914**, the second position signal is reported.

FIG. **10** shows a flowchart of an exemplary process for processing a position signal, in accordance with an embodiment of the present invention. The blocks of flowchart **1000** may be performed by a data processing portion (e.g., data processing module **212** or data processing module **514**) of a

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sensor circuit (e.g., sensor circuits **200** and **400-600**). It is appreciated that blocks or select blocks of flowchart **1000** may be repeated as the position signal (e.g., centroid) moves around an array of capacitive sensors.

At block **1002**, the array of capacitive sensors is in a low sensitivity mode with all sensors scanned. In one embodiment, the array of capacitive sensors may operate in a low sensitivity mode while no interactions with the array are detected.

At block **1004**, whether an interaction with the array of capacitive sensors has occurred is detected. If there is no interaction detected, the capacitive sensor array remains in low sensitivity mode at block **1002**. If an interaction is detected, the capacitive sensor array may proceed to block **1006**.

At block **1006**, a first position signal is received from a plurality of active capacitive sensors. As described herein, the first position signal may be coupled from a centroid and may be received from a plurality of capacitive sensors which are part of an array of capacitive sensors.

At block **1008**, a proximity of the plurality of active capacitive sensors to a connection of an array of capacitive sensors is determined. As described herein, the relative locations of one or more capacitive sensors to the connections of an array of capacitive sensors may be determined.

At block **1010**, the sensitivity of the active capacitive sensors in the array of capacitive sensors is adjusted. The sensitivity of one or more capacitive sensors may be adjusted to increase the resolution and signal level, thereby compensating for the impact of the impedance of an array of capacitive sensors. Adjusting the sensitivity of the active capacitive sensors saves power over increasing the sensitivity of all the capacitive sensors.

The sensitivity of the capacitive sensors may be adjusted by adjusting the scan time of the capacitive sensors. As described herein, the scan time of an individual sensor circuit may be adjusted by adjusting the current (e.g., lowering the current) for charging a capacitor of a current source (e.g., current source **204**), adjusting a pulse width modulation (e.g., of pulse width modulator **410**), a voltage threshold (e.g., reference voltage **226** or **422**), or adjusting a capacitance of an integration capacitor (e.g., external modification capacitor **428**). In one embodiment, the adjustment of the scan time increases the resolution and signals levels by increasing the detection period (e.g., phase 2 of circuit **200**). It is appreciated that adjusting the scan time of the active capacitive sensors saves scan time over increasing the scan time of the entire array of capacitive sensors.

In one embodiment, the scan time may be adjusted according to the position of one or more active capacitive sensors. For example, the scan time of sensors in the upper left could be increased more than the scan time in the middle of a capacitive sensor array where the connections of the array are in the lower right. In one embodiment, each sensor may have a respective adjustment factor that is based on its distance from the detecting logic.

At block **1012**, a second position signal is received from the plurality of active capacitive sensors with heightened sensitivity. The second position signal may be received after the sensitivity of the sensors has been adjusted as described herein. At block **1014**, the second position signal is reported.

Thus, embodiments of the present invention compensate for the impedance of an array of capacitive sensors. Thus, a substantial improvement in accuracy and performance of arrays of capacitive sensors is achieved.

Embodiments of the present invention are thus described. While the present invention has been described in particular

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embodiments, it should be appreciated that the present invention should not be construed as limited by such embodiments, but rather construed according to the below claims.

What is claimed is:

1. A method for reporting position information, the method comprising:

adjusting position information received from a plurality of capacitive sensors in an array of capacitive sensors based on predetermined adjustment values to generate adjusted position information, wherein each predetermined adjustment value is associated with at least one of the plurality of capacitive sensors, and wherein each predetermined adjustment value is derived from a distance between the at least one of the plurality of capacitive sensors and a connection of the array of capacitive sensors; and

generating a signal representative of the adjusted position information.

2. The method of claim 1, wherein each predetermined adjustment value is derived from a position of the at least one of the plurality of capacitive sensors within the array of capacitive sensors.]

3. The method of claim 1, wherein each predetermined adjustment value is a scalar value, and the predetermined adjustment values are stored in a matrix corresponding to the array of capacitive sensors.

4. The method of claim 3, wherein the adjusting of the position information comprises multiplying the position information received from the plurality of capacitive sensors by the respective predetermined adjustment values.

5. The method of claim 1, further comprising performing a centroid computation based on the adjusted position information.

6. The method of claim 1, wherein the array of capacitive sensors comprises a high impedance substrate.

7. A method for reporting position information comprising:

adjusting the sensitivity of at least one capacitive sensor in a capacitive sensor array based on a distance between the at least one capacitive sensor and a connection of the capacitive sensor array;

receiving position information from the at least one capacitive sensor; and

generating a signal representative of the position information.

8. The method of claim 7, further comprising generating the position information with the at least one capacitive sensor, wherein the generating of the position information comprises charging the at least one capacitive sensor based on the operation of a switch.

9. The method of claim 8, wherein the operation of the switch is controlled by a pseudo random generator.

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10. The method of claim 7, wherein the adjusting of the sensitivity of the at least one capacitive sensor comprises adjusting a scan time of the at least one capacitive sensor.

11. The method of claim 10, wherein the adjusting of the scan time of the at least one capacitive sensor comprises adjusting a current source coupled to the at least one capacitive sensor.

12. The method of claim 10, wherein the adjusting of the scan time of the at least one capacitive sensor comprises adjusting the pulse width modulation of a pulse width modulator.

13. The method of claim 10, wherein the at least one capacitive sensor is coupled to a capacitor, and the adjusting of the scan time of the at least one capacitive sensor comprises adjusting a reference voltage to which a voltage across the capacitor is compared.

14. The method of claim 10, wherein the at least one capacitive sensor is coupled to a capacitor, and the adjusting of the scan time of the at least one capacitor comprises adjusting the capacitance of the capacitor.

15. *A method for reporting position information, the method comprising:*

storing a plurality of predetermined adjustment values, wherein each predetermined adjustment value is associated with at least one of a plurality of capacitive sensors in an array of capacitive sensors, and wherein each predetermined adjustment value is derived from a distance between at least one of the plurality of capacitive sensors and a connection of the array of capacitive sensors; and

generating a signal based on the predetermined adjustment values and received position information.

16. *The method of claim 15, wherein generating the signal further comprises adjusting position information received from the plurality of capacitive sensors based on the stored predetermined adjustment values to generate adjusted position information.*

17. *The method of claim 15, wherein each predetermined adjustment value is a scalar value, and the predetermined adjustment values are stored in a matrix corresponding to the array of capacitive sensors.*

18. *The method of claim 17, further comprising adjusting the position information by multiplying the received position information by the respective predetermined adjustment values.*

19. *The method of claim 15, further comprising performing a centroid computation based on the adjusted position information.*

20. *The method of claim 15, wherein the array of capacitive sensors comprises a high impedance substrate.*

* * * * *