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(54) **CAPACITIVE SENSING SYSTEM**

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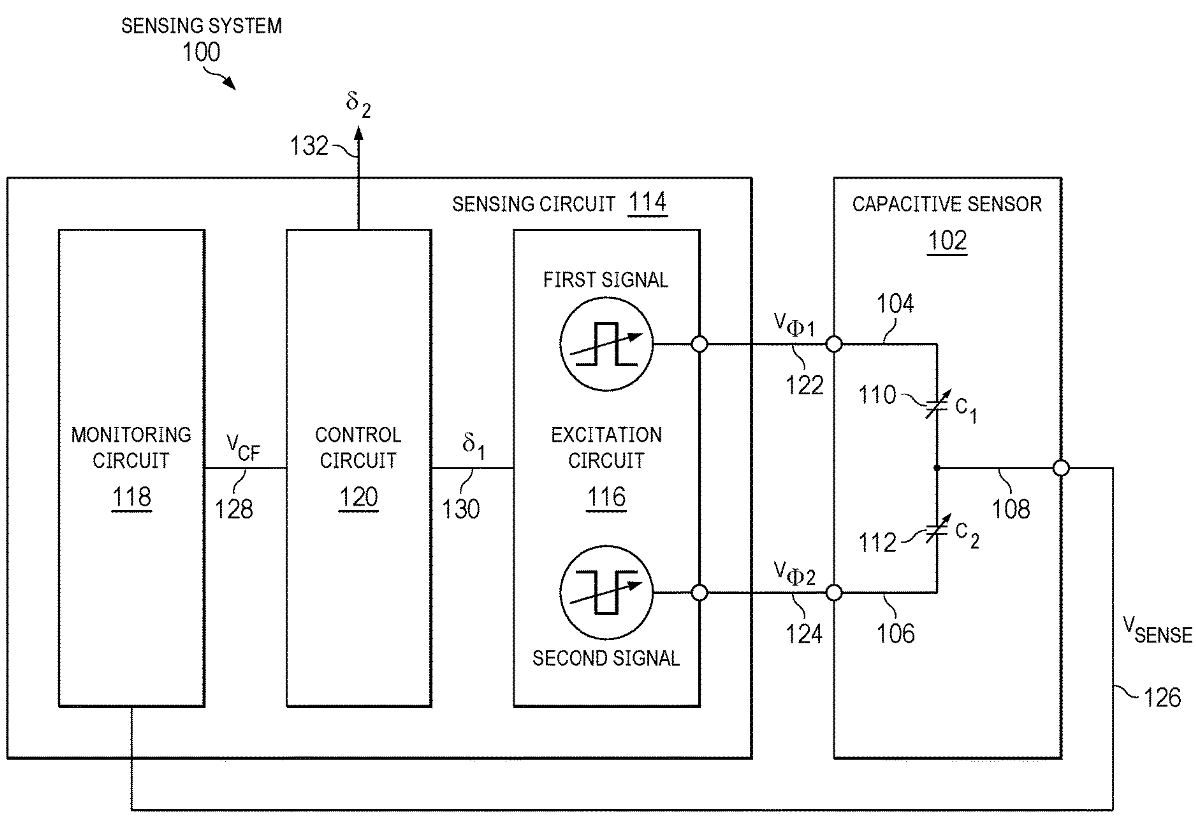
(57) **ABSTRACT**

A capacitive sensing system may include a capacitive sensor and a sensing circuit. The sensing circuit may include an excitation circuit, a monitoring circuit, and a control circuit. The excitation circuit may provide a first signal of a first frequency and a second signal of a second frequency to the capacitive sensor to generate a third signal. The monitoring circuit may receive the third signal and generate an output signal based on the third signal. Based on the output signal from the monitoring circuit, the control circuit may control the first frequency of the first signal and/or the second frequency of the second signal to determine a value of the third signal.



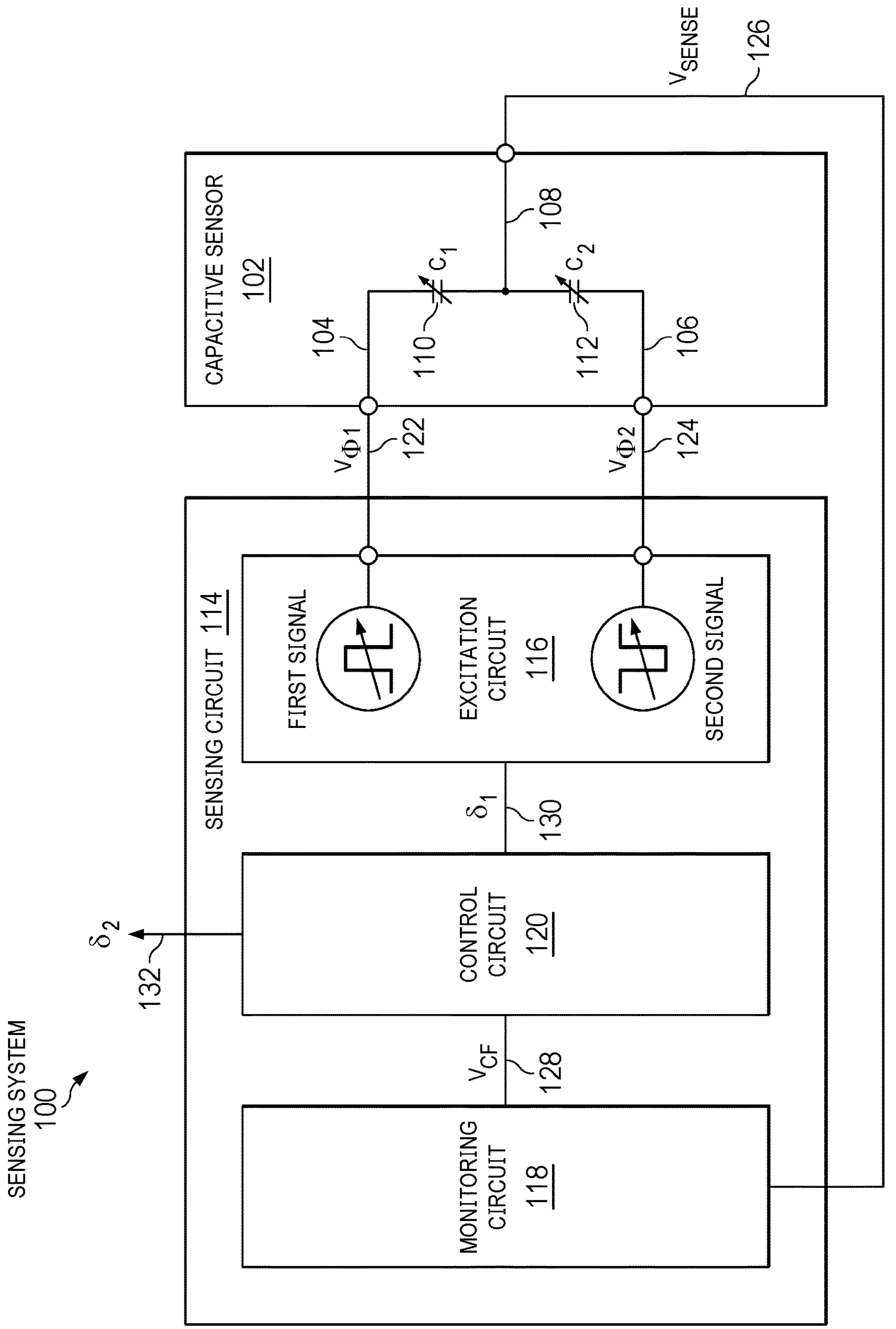

SENSING SYSTEM
100
SENSING CIRCUIT 114
CAPACITIVE SENSOR
102
V_{SENSE}
126
104
106
108
110
112
C_1
C_2
$V_{\Phi 1}$
122
$V_{\Phi 2}$
124
FIRST SIGNAL
EXCITATION
CIRCUIT
116
SECOND SIGNAL
δ_1
130
CONTROL
CIRCUIT
120
δ_2
132
V_{CF}
128
MONITORING
CIRCUIT
118

FIG. 1

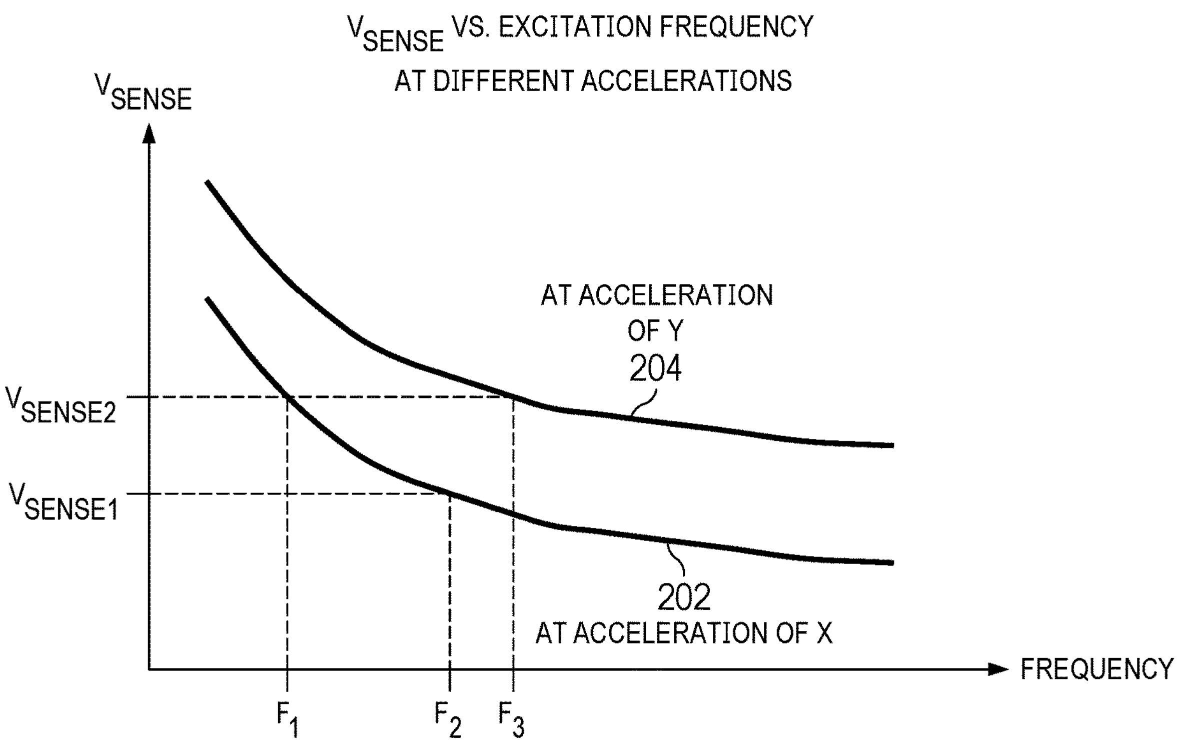

V_{SENSE} VS. EXCITATION FREQUENCY
AT DIFFERENT ACCELERATIONS
V_{SENSE}
AT ACCELERATION
OF Y
204
V_{SENSE2}
V_{SENSE1}
202
AT ACCELERATION OF X
FREQUENCY
F_1
F_2
F_3

FIG. 2

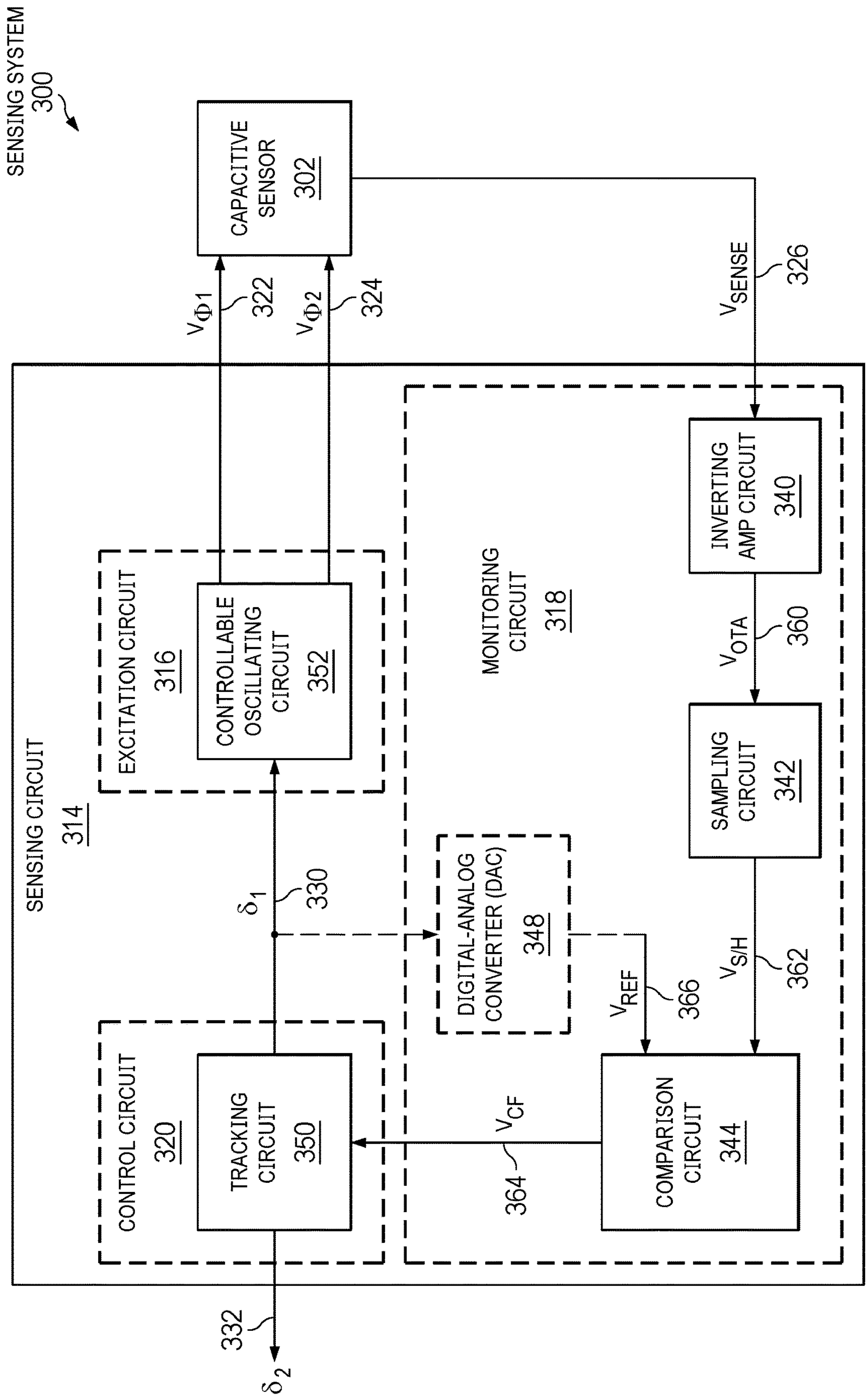

SENSING SYSTEM
300
CAPACITIVE SENSOR
302
$V_{\Phi 1}$
322
$V_{\Phi 2}$
324
V_{SENSE}
326
SENSING CIRCUIT
314
EXCITATION CIRCUIT
316
CONTROLLABLE OSCILLATING CIRCUIT
352
MONITORING CIRCUIT
318
INVERTING AMP CIRCUIT
340
V_{OTA}
360
SAMPLING CIRCUIT
342
$V_{S/H}$
362
δ_1
330
DIGITAL-ANALOG CONVERTER (DAC)
348
V_{REF}
366
CONTROL CIRCUIT
320
TRACKING CIRCUIT
350
V_{CF}
364
COMPARISON CIRCUIT
344
332
δ_2

FIG. 3

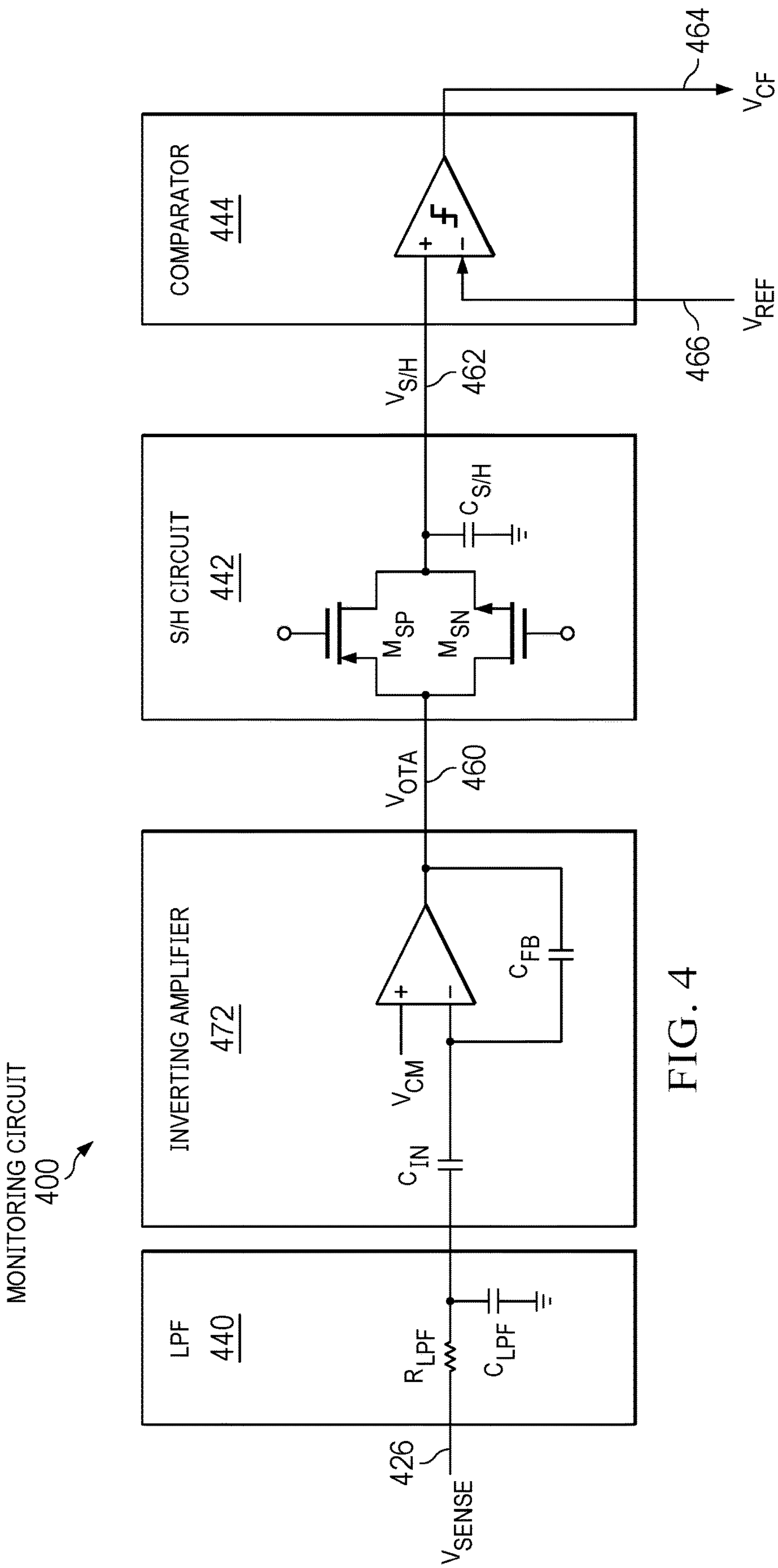

MONITORING CIRCUIT
400
LPF
440
INVERTING AMPLIFIER
472
S/H CIRCUIT
442
COMPARATOR
444
V_{SENSE}
426
R_{LPF}
C_{LPF}
C_{IN}
V_{CM}
C_{FB}
V_{OTA}
460
M_{SP}
M_{SN}
$C_{S/H}$
$V_{S/H}$
462
V_{REF}
466
V_{CF}
464

FIG. 4

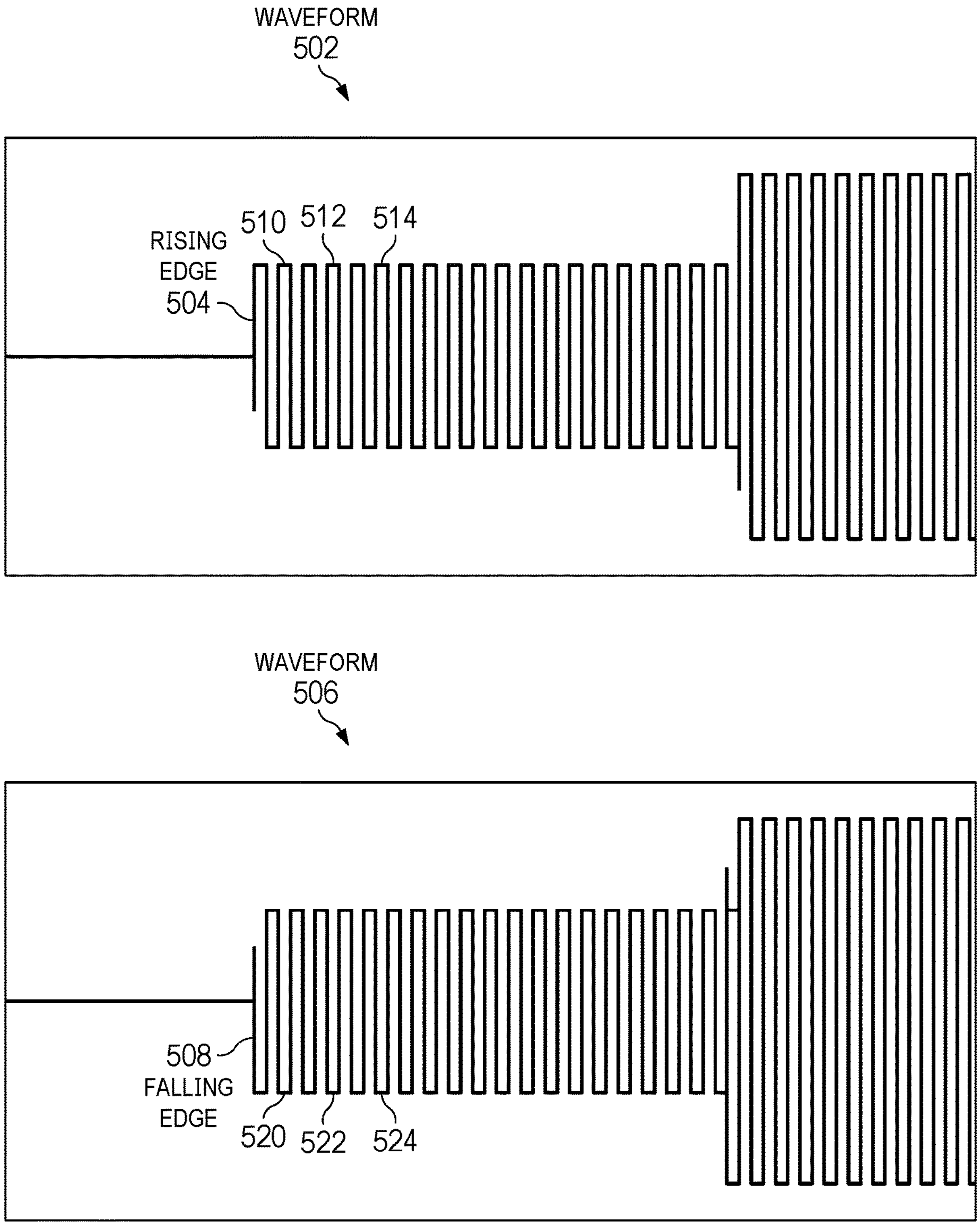

WAVEFORM
502
RISING
EDGE
504
510
512
514
WAVEFORM
506
508
FALLING
EDGE
520
522
524

FIG. 5

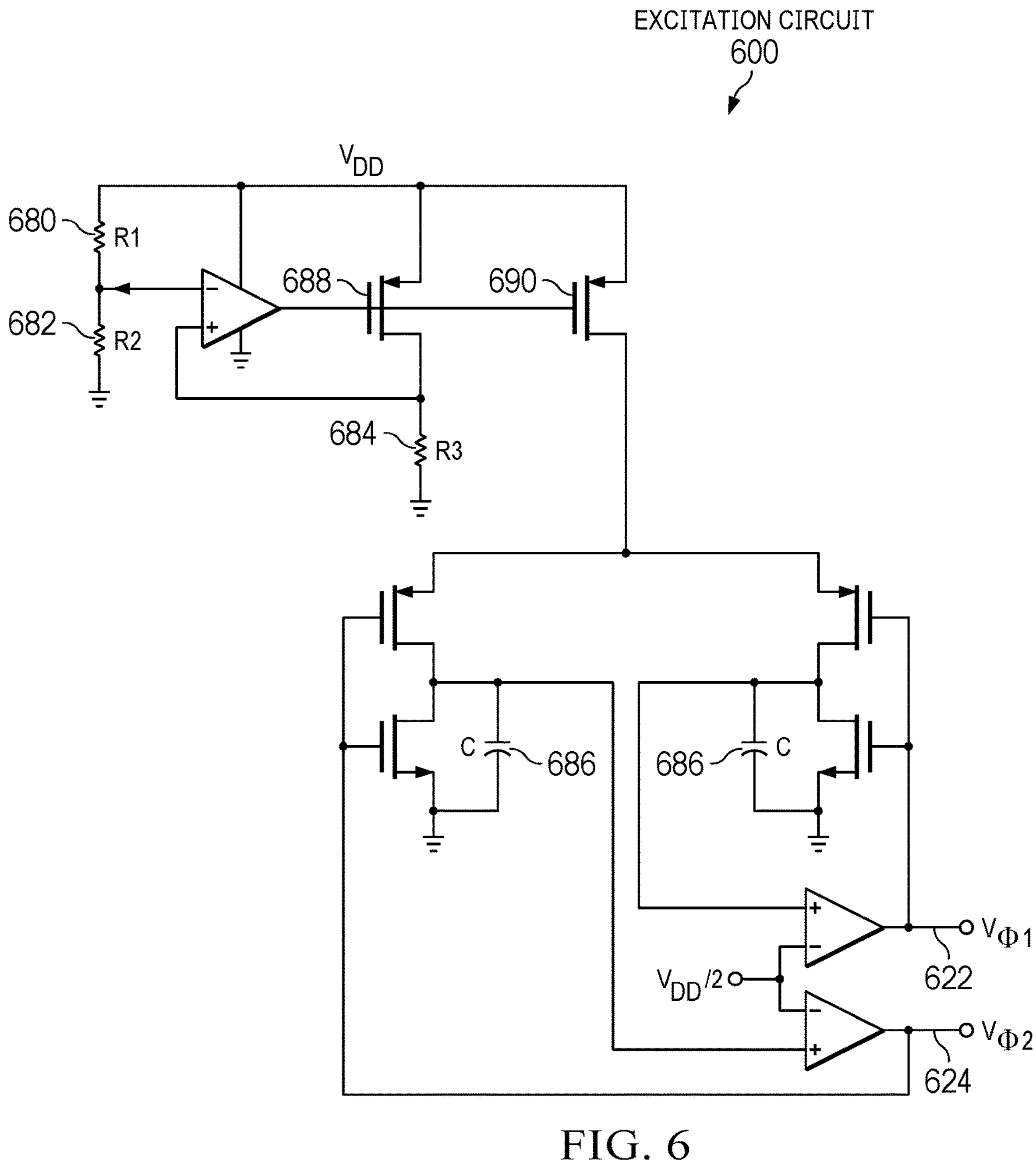

EXCITATION CIRCUIT
600
V_{DD}
680
R1
682
R2
688
690
684
R3
C
686
C
686
$V_{DD}/2$
$V_{\Phi 1}$
622
$V_{\Phi 2}$
624

FIG. 6

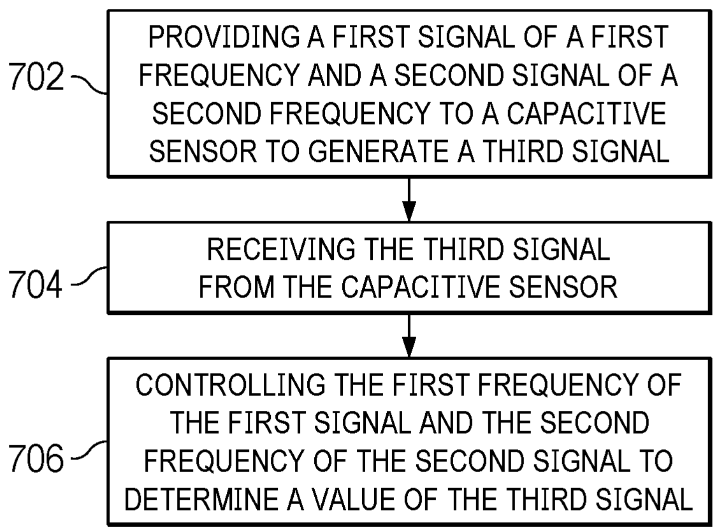

702
PROVIDING A FIRST SIGNAL OF A FIRST FREQUENCY AND A SECOND SIGNAL OF A SECOND FREQUENCY TO A CAPACITIVE SENSOR TO GENERATE A THIRD SIGNAL
704
RECEIVING THE THIRD SIGNAL FROM THE CAPACITIVE SENSOR
706
CONTROLLING THE FIRST FREQUENCY OF THE FIRST SIGNAL AND THE SECOND FREQUENCY OF THE SECOND SIGNAL TO DETERMINE A VALUE OF THE THIRD SIGNAL

FIG. 7

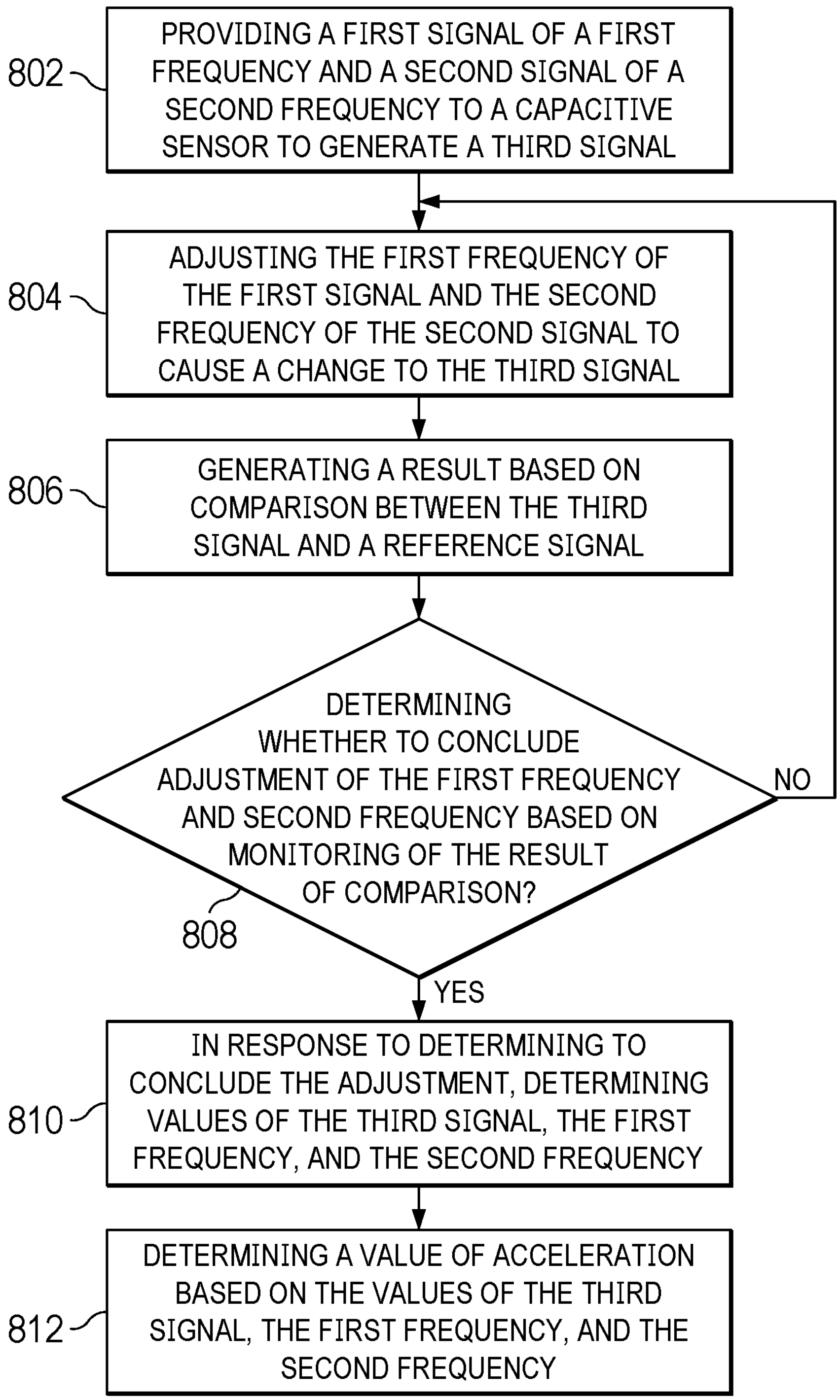

802
PROVIDING A FIRST SIGNAL OF A FIRST FREQUENCY AND A SECOND SIGNAL OF A SECOND FREQUENCY TO A CAPACITIVE SENSOR TO GENERATE A THIRD SIGNAL
804
ADJUSTING THE FIRST FREQUENCY OF THE FIRST SIGNAL AND THE SECOND FREQUENCY OF THE SECOND SIGNAL TO CAUSE A CHANGE TO THE THIRD SIGNAL
806
GENERATING A RESULT BASED ON COMPARISON BETWEEN THE THIRD SIGNAL AND A REFERENCE SIGNAL
DETERMINING WHETHER TO CONCLUDE ADJUSTMENT OF THE FIRST FREQUENCY AND SECOND FREQUENCY BASED ON MONITORING OF THE RESULT OF COMPARISON?
808
NO
YES
810
IN RESPONSE TO DETERMINING TO CONCLUDE THE ADJUSTMENT, DETERMINING VALUES OF THE THIRD SIGNAL, THE FIRST FREQUENCY, AND THE SECOND FREQUENCY
812
DETERMINING A VALUE OF ACCELERATION BASED ON THE VALUES OF THE THIRD SIGNAL, THE FIRST FREQUENCY, AND THE SECOND FREQUENCY

FIG. 8

CAPACITIVE SENSING SYSTEM

TECHNICAL FIELD

[0001] This disclosure generally relates to sensors, and in particular, to capacitive sensor based sensing systems.

BACKGROUND

[0002] Capacitive sensors can be used in many applications. For example, in the automotive industry, capacitive accelerometers can be installed in a tire-pressure monitoring system (TPMS) to measure acceleration of an automotive. The measurement can further be used to implement functions such as automotive airbags, navigation, and instrumentation. In another example, capacitive sensors can be used to implement capacitive transducers in microphones for audio equipment to convert sound to electrical signals. Capacitive sensors perform the functions based on detecting a change in capacitance within the sensors caused by external force. Traditionally, a capacitive sensing system can have noise and jitter issues, which affect its sensing sensitivity and reliability. Further, sometimes capacitive sensors can have a long shelf time before putting in use, and thus low power and low leakage current while idle can be required. Thus, it is desired to have a low-noise and low-power solution for capacitive sensing.

SUMMARY

[0003] This disclosure describes a capacitive sensor based sensing system (hereinafter "capacitive sensing system"). In some examples, the capacitive sensing system may include a sensing circuit and a capacitive sensor. The sensing circuit may provide excitation signals to modulate the capacitive sensor, and in response the capacitive sensor may generate an output signal. Based on the output signal, the sensing circuit may determine a change in capacitance of the capacitive sensor. The information may further be provided to a processor to implement other application-specific functions. In particular, in some examples, the frequency of the excitation signals may be controllably varied by the sensing circuit, instead of being held at a constant value, to determine the value of the output signal. For example, in some examples, the output signal may be compared with a reference signal, e.g., by a comparator, to generate a signal, e.g., a digital signal having a binary value. The value may indicate a result of the comparison, e.g., whether the output signal is less than, or not less than, the reference signal. For purposes of illustration, when the output signal becomes not less than the reference signal, the comparator may be considered "triggered," whereas when the output signal is less than the reference signal, the comparator may be considered "untriggered." Thus, when the comparator is triggered, the sensing circuit may determine that the value of the output signal is equal to, or at least not less than, the value of the reference signal. In some examples, the sensing circuit may iteratively change the frequency of the excitations signals back and forth. In turn, the change of the excitation frequency may change the output signal and thus repeatedly trigger and untrigger the comparator. As a result, the sensing circuit may iteratively narrow the range of the varied frequency to determine a closest frequency that triggers the comparator at the value of the reference signal. In other words, the sensing circuit may determine the value of the output signal (e.g., equal to the value of the reference signal) and the corresponding closest frequency at which the capacitive sensor is excited to generate the output signal of the same value as the reference signal. In some examples, for example, for a capacitive accelerometer, the output signal may be a function of acceleration (to be measured) at any specific excitation frequency. Thus, given the closest excitation frequency and the determined value of the output signal, the sensing circuit may further determine a value of the acceleration. The variation of the excitation frequency may create an extra control freedom to improve performance of the capacitive sensing system. For example, in some examples, by lowering the frequency, the output voltage-to-change of capacitance ratio (also called the "gain") of the capacitive sensing system may be increased, which may thus increase the signal-to-noise ratio (SNR) to mitigate noise and jitter effects.

[0004] In some examples, the sensing circuit may include an excitation circuit, a monitoring circuit, and a control circuit. The excitation circuit may include a first output terminal and a second output terminal. The excitation circuit may be configured to provide a first signal of a first frequency to the capacitive sensor via the first output terminal, and a second signal of a second frequency to the capacitive sensor via the second output terminal. In some examples, the first frequency may be the same as the second frequency, and the first signal may have a phase shift relative to the second signal. In some examples, the phase shift may be 180 degrees, or in other words, the first signal may be out of phase relative to the second signal. In some examples, the monitoring circuit may include an input terminal configured to receive a third signal generated from the capacitive sensor in response to the first and second signals. In some examples, the control circuit may be configured to control the first frequency of the first signal and/or the second frequency of the second signal to determine a value of the third signal.

[0005] In some examples, a method for performing sensing based on a capacitive sensor may include providing a first signal of a first frequency and a second signal of a second frequency to a capacitive sensor to generate a third signal. In some examples, the first frequency may be equal to the second frequency, and the first signal may have a phase shift relative to the second signal. In some examples, the phase shift may be 180 degrees, or in other words, the first signal may be out of phase relative to the second signal. The method may further include receiving the third signal from the capacitive sensor (which is generated by the capacitive sensor in response to the first and second signals). The method may further include controlling the first frequency of the first signal and/or the second frequency of the second signal to determine a value of the third voltage.

[0006] In some examples, a device may include a sensing circuit configured to determine acceleration based on a capacitive sensor. In some examples, the sensing circuit may provide a first signal of a first frequency and a second signal of a second frequency to a capacitive sensor to generate a third signal. The sensing circuit may adjust the first frequency and/or the second frequency, which may in turn change the third signal. The sensing circuit may generate an output signal based on a reference signal and the third signal. The sensing circuit may determine whether to conclude adjustment of the first and/or second frequencies based on the output signal, and in response to determining to conclude adjustment of the first and/or second frequencies, determine values of the third signal, the first frequency, and/or the second frequency. The sensing circuit may determine a value of acceleration based on the values of the third signal, the first frequency, and/or the second frequency.

[0007] In some examples, a method for determining acceleration based on a capacitive sensor may include providing a first signal of a first frequency and a second signal of a second frequency to a capacitive sensor to generate a third signal. The method may include adjusting the first frequency and/or the second frequency, which may in turn change the third signal. The method may include generating an output signal based on a reference signal and the third signal. The method may include determining whether to conclude adjustment of the first and/or second frequencies based on the output signal, and in response to determining to conclude adjustment of the first and/or second frequencies, determining values of the third signal, the first frequency, and/or the second frequency. The method may include determining a value of acceleration based on the values of the third signal, the first frequency, and/or the second frequency.

[0008] These and other features and implementations will be better understood from the following detailed description with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] So that the manner in which the above recited features can be understood in detail, a more particular description, briefly summarized above, may be had by reference to example implementations, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical example implementations and are therefore not to be considered limiting of its scope.

[0010] FIG. **1** is a block diagram illustrating an example capacitive sensing system, according to some examples.

[0011] FIG. **2** is a diagram illustrating an example relationship between output signal and excitation frequency of a capacitive sensor at different acceleration, according to some examples.

[0012] FIG. **3** is a block diagram illustrating an example capacitive sensing system in more detail, according to some examples.

[0013] FIG. **4** is a block diagram illustrating an example monitoring circuit, according to some examples.

[0014] FIG. **5** is a diagram illustrating an example relationship between output signal and acceleration of a capacitive sensor, according to some examples.

[0015] FIG. **6** is a block diagram illustrating an example excitation circuit, according to some examples.

[0016] FIG. **7** is a flowchart illustrating an example method for performing sensing based on a capacitive sensor, according to some examples.

[0017] FIG. **8** is a flowchart illustrating an example method for performance sensing of acceleration based on a capacitive sensor, according to some embodiments.

[0018] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements of one example may be beneficially incorporated in other examples.

DETAILED DESCRIPTION

[0019] Various features are described hereinafter with reference to the figures. It should be noted that the figures may or may not be drawn to scale and that the elements of similar structures or functions are represented by like reference numerals throughout the figures. It should be noted that the figures are only intended to facilitate the description of the features. They are not intended as an exhaustive description of the description or as a limitation on the scope of the claims. In addition, an illustrated example need not have all the aspects or advantages shown. An aspect or an advantage described in conjunction with a particular example is not necessarily limited to that example and can be practiced in any other examples even if not so illustrated, or if not so explicitly described.

[0020] FIG. **1** is a block diagram illustrating an example capacitive sensing system, according to some examples. As shown in FIG. **1**, in some examples, capacitive sensing system **100** may include capacitive sensor **102** and sensing circuit **114**. For purposes of illustration, in FIG. **1**, capacitive sensor **102** is represented by a simplified model including three conductive plates, e.g., top plate **104**, middle plate **108**, and bottom plate **106**. In some examples, the three conductive plates may be arranged substantially in parallel to create top capacitor C**1** **110** between top plate **104** and middle plate **108**, and bottom capacitor C**2** **112** between middle plate **108** and bottom plate **106**. In some examples, top plate **104** and bottom plate **106** may be arranged to stay stationary, whereas middle plate **108** may be movable, or vice versa. Thus, external force may cause a displacement in distance between top plate **104** and middle plate **108**, and a displacement in distance between middle plate **108** and bottom plate **106**. The displacements may change capacitance of top capacitor C**1** **110** and bottom capacitor C**2** **112**. In some examples, in equilibrium the capacitance of the two capacitors may be the same, whereas during movements the two capacitance may move in an opposite direction with the summation of the capacitance being a constant value. Note that FIG. **1** is provided only as an example for purposes of illustration. In some examples, capacitive sensor **102** may include more sets of plates beyond plates **104**, **106**, and **108**. Thus, the capacitance formed by each pair of plates may appear in parallel and/or series to each other, allowing for a better resolution for measurement.

[0021] As shown in FIG. **1**, in some examples, sensing circuit **114** may include excitation circuit **116**, monitoring circuit **118**, and control circuit **120**. In some examples, excitation circuit **116** may generate first signal Φ_1 and second signal Φ_2. In some examples, Φ_1 and Φ_2 may be repetitive voltage signals $V_{\Phi 1}$ **122** and $V_{\Phi 2}$ **124** having respectively a first frequency and a second frequency. For example, $V_{\Phi 1}$ **122** and $V_{\Phi 2}$ **124** may be pulse-shaped voltage signals, sinusoidal voltage signals, etc. In some examples, the first frequency of $V_{\Phi 1}$ **122** may be equal to the second frequency of $V_{\Phi 2}$ **124**. Additionally, in some example, $V_{\Phi 1}$ **122** may have a phase shift relative to $V_{\Phi 2}$ **124**. In some examples, the phase shift may be 180 degrees, or in other words, $V_{\Phi 1}$ **122** may be out of phase relative to $V_{\Phi 2}$ **124**. Moreover, in some examples, $V_{\Phi 1}$ **122** may have the same amplitude as $V_{\Phi 2}$ **124**. Alternatively, in some examples, the first frequency may be different from the second frequency, the phase shift may be different other than 180 degrees, and/or the two signals may have different amplitudes.

[0022] As shown in FIG. **1**, in some examples, excitation circuit **114** may have a first output terminal and a second terminal. Additionally, capacitive sensor **102** may have a first input terminal, a second input terminal, and an output terminal. The first input terminal of capacitive sensor **102** may be coupled to top plate **104**, the second input terminal may be coupled to bottom plate **106**, and the output terminal may be coupled to middle plate **108**. In other words, capacitive sensor **102** may include top capacitor C1 **110** between the first input terminal and the output terminal, and bottom capacitor C2 **112** between the output terminal and the second input terminal. In some examples, excitation circuit **114** may inject first voltage signal $V_{\Phi 1}$ **122** through the first output terminal to the first input terminal of capacitive sensor **102**, and second output signal $V_{\Phi 2}$ **124** through the second output terminal to the second input terminal of capacitive sensor **102**. $V_{\Phi 1}$ **122** and $V_{\Phi 2}$ **124** may serve as excitation to stimulate capacitive sensor **102**, which may in response generate an output signal, e.g., output voltage V_{sense} **126**, through the output terminal of capacitive sensor **102**. As described above, external force, e.g., caused by acceleration, may change the capacitance of top capacitor C1 **110** and bottom capacitor C2 **112**, which may in turn be reflected in output voltage V_{sense} **126**. Additionally, variation in the frequency of excitation signals $V_{\Phi 1}$ **122** and $V_{\Phi 2}$ **124** may also change output voltage V_{sense} **126**. Thus, given output voltage V_{sense} **126** and excitation frequency, the corresponding acceleration may be determined. In some examples, the frequency of excitation signals $V_{\Phi 1}$ **122** and $V_{\Phi 2}$ **124** may be controlled to increase output voltage V_{sense} **126** to thus increase the output voltage-to-change of capacitance ratio or gain of capacitive sensing system **100**.

[0023] Referring back to FIG. **1**, in some examples, monitoring circuit **118** may receive output voltage V_{sense} **126** from capacitive sensor **102**, which is generated by capacitive sensor **102** in response to excitation signals $V_{\Phi 1}$ **122** and $V_{\Phi 2}$ **124**. In some examples, monitoring circuit **118** may generate signal V_{CF} **128** based on output voltage V_{sense} **126** with a reference signal e.g., a reference voltage V_{REF}. For example, in some examples, monitoring circuit **118** may include a comparison circuit that may compare output voltage V_{sense} **126** with V_{REF} to generate V_{CF} **128**. Thus, V_{CF} **128** may indicate whether output voltage V_{sense} **126** is less than, or not less than, V_{REF}. In some examples, monitoring circuit **118** may use V_{CF} **128** to monitor the change of V_{sense} **126** in response to variation of the first frequency of $V_{\Phi 1}$ **122** and/or the second frequency of $V_{\Phi 2}$ **124**. For purposes of illustration, when V_{sense} **126** becomes not less than V_{REF}, the comparison circuit may be considered "triggered," whereas when V_{sense} **126** is less than V_{REF}, the comparison circuit may be considered "untriggered." Thus, triggering of the comparison circuit implies that V_{sense} **126** is equal to, or at least not less than, V_{REF}, and untriggering of the comparison circuit implies that V_{sense} **126** is less than V_{REF}.

[0024] As shown in FIG. **1**, in some examples, control circuit **120** may receive output signal V_{CF} **128** from monitoring circuit **118**, which is generated based on output voltage V_{sense} **126**. As described above, in some examples, variation of the first frequency of $V_{\Phi 1}$ **122** and/or the second frequency of $V_{\Phi 2}$ **124** may cause a change to output voltage V_{sense} **126**, which may further cause a change to V_{CF} **128**. For example, the variation of the first and/or second frequencies may increase or decrease V_{sense} **126**, which may trigger or untrigger the comparison circuit of monitoring circuit **118**. This may be represented by V_{CF} **128**. In some examples, control circuit **120** may iteratively change (through excitation circuit **114**) the first and/or second frequencies back and forth. In turn, the change of the first and/or second frequencies may repeatedly trigger and untrigger the comparison circuit. Thus, based on V_{CF} **128**, control circuit **120** may iteratively narrow the range of the first and/or second frequencies to determine closest first and/or second frequencies that trigger the comparison circuit at the value of V_{REF}. In other words, control circuit **120** may determine the value of V_{sense} **126** (e.g., equal to the value of V_{REF}) and the corresponding closest first and/or second frequencies at which capacitive sensor **102** generates V_{sense} **126** of the same value as V_{REF}. In some examples, for example, for a capacitive accelerometer, V_{sense} **126** may be a function of acceleration (to be measured) at any specific excitation frequencies. Thus, given the determined value of V_{sense} **126** and first and/or second frequencies, control circuit **120** may further determine a value of acceleration.

[0025] In some examples, control circuit **120** may provide δ_1 **130** to excitation circuit **116** to control the first frequency of first excitation signal $V_{\Phi 1}$ **122** and/or the second frequency of second excitation signal $V_{\Phi 2}$ **124**. For example, excitation circuit **116** may include an oscillator and a divisor. Excitation circuit **114** may divide a clock signal generated from the oscillator by the divisor to generate a divided clock signal, which may further be used to generate $V_{\Phi 1}$ **122** and $V_{\Phi 2}$ **124**. Accordingly, δ_1 **130** may indicate a value or change to the value of the divisor. Thus, by providing δ_1 **130** to excitation circuit **116**, control circuit **120** may adjust the frequencies of $V_{\Phi 1}$ **122** and/or $V_{\Phi 2}$ **124**. In another example, excitation circuit **114** may include a relaxation oscillating circuit configured to generate $V_{\Phi 1}$ **122** and $V_{\Phi 2}$ **124**, where the frequencies of $V_{\Phi 1}$ **122** and $V_{\Phi 2}$ **124** may depend on values of a set of resistors. Accordingly, δ_1 **130** may indicate a value or change to the value of at least one of the resistors, and accordingly the frequencies of $V_{\Phi 1}$ **122** and/or V_{12} **124** may be adjusted by control circuit **120**.

[0026] As shown in FIG. **1**, in some examples, control circuit **120** may provide signal δ_2 **132** to a processor (not shown). For example, as described above, if capacitive sensor **102** is a capacitive accelerometer for a TPMS of an automotive, control circuit **132** may determine a value of acceleration. Thus, δ_2 **132** may include the determined value of acceleration. In response to receiving δ_2 **132**, the processor may implement other functions such as automotive airbags, navigation, and instrumentation. In some examples, the processor or control circuit **120** of sensing circuit **114** may identify an "optimal" frequency amongst the varied first and/or second frequencies to operate capacitive sensor **102**. In practice, different capacitive sensors may have different properties and thus require different optimal frequencies to operate. Thus, sensing circuit **114** may be fit for various sensor by automatically adjusting excitation signals for optimal performance when used with those sensors.

[0027] In some examples, sensing circuit **114** may be configured to operate in a regular mode and a relatively low power mode. In some examples, sensing circuit **114** may self-determine whether to switch from the regular mode to the low power mode. For example, sensing circuit **114** may determine that no acceleration and/or no change of acceleration is detected within a certain time period (e.g., during idle), and thus switch to the low power mode to save energy for the system. Alternatively, in some examples, switching of modes may be controlled by external signal(s). For example, a processor may provide a trigger signal to enable the low power mode or wake up sensing circuit **114** from the low power mode to the regular mode.

[0028] In some examples, sensing circuit **114** may be implemented using an integrated circuit (IC) or a system on a chip (SOC). Additionally, in some examples, capacitive system **100**, including both capacitive sensor **102** and sensing circuit **114**, may be integrated into one IC or SOC. Further, in some examples, capacitive sensor **102** may be a micro-electromechanical system (MEMS) capacitive accelerometer, and sensing circuit **112** may be the corresponding sensing circuit, both of which may be associated with a TPMS of an automotive.

[0029] The disclosed sensing system may provide at least several benefits. For example, traditionally a sensing circuits injects only one single excitation signal at a constant frequency to modulate a capacitive sensor. By comparison, sensing circuit **114** as disclosed herein may provide two excitation signals $V_{\Phi 1}$ **122** and $V_{\Phi 2}$ **124** of variable frequencies to modulate a capacitive sensor. As described above, the variation of the frequencies of the excitation signals may create extra control freedom to increase the gain and SNR of the capacitive sensing system and thus reduce the noise and jitter effects. Additionally, as described above, sensing system **100** with the self-tuning capability may be used with different capacitive sensors, requiring minimum adjustments by customers. For example, in some examples, sensing circuit **114** may sweep the frequencies of $V_{\Phi 1}$ **122** and $V_{\Phi 2}$ **124** within a range to cause capacitive sensor **102** to generate output signal V_{sense} **126** at different excitation frequencies. For a given capacitive sensor, the information may be processed to identify an optimal excitation frequency to operate the sensor.

[0030] Note that FIG. **1** is provided only as an example for purposes of illustration. In some examples, sensing circuit **114** may provide only one signal of a variable frequency to modulate capacitive sensor **102**. For example, sensing circuit **114** may inject one single variable-frequency excitation voltage to middle plate **108** of capacitive sensor **102** and measure the output voltage generated between top plate **104** and bottom plate **106**. The remaining operations of sensing circuit **114** may be similar to what is described above. For example, the output signal may be received by monitoring circuit **116** which may generate an output signal (e.g., from comparison) based on the output signal of the capacitive sensor. Based on the output signal of the monitoring circuit, control circuit **118** may control the frequency of the excitation voltage to determine a value of the output signal of the capacitive sensor. Additionally, in some examples, besides the above described frequency modulation, sensing circuit **114** may modulate the amplitude(s) and/or phase(s) of the excitation signal(s) to perform measurement based on capacitive sensor **102**. Moreover, sensing circuit **114** may also apply to an inductive sensor. For examples, in some examples, sensing circuit **114** may inject one or more variable-frequency excitation signals to modulate an inductive sensor, which may in response generate an output signal. Sensing circuit **114** may receive the output signal and control the frequencies of the excitation signals to determine a value of the output signal of the inductive sensor.

[0031] FIG. **2** is a diagram illustrating an example relationship between output signal and excitation frequency of a capacitive sensor at different acceleration, according to some examples. In FIG. **2**, the horizontal axis represents the frequency of excitation signals (e.g., $V_{\Phi 1}$ **122** and $V_{\Phi 2}$ **124**, assuming that the two signals have the same frequency), and the vertical axis represents the value of an output signal of a capacitive sensor (e.g., V_{sense} **126** of capacitive sensor **102**). In FIG. **2**, curve **202** represents the output signal at a first acceleration of x, whereas curve **204** represents the output signal at a second acceleration of y. As shown by curve **202**, at one given acceleration (e.g., acceleration of x), the output signal may change monotonically with the excitation frequency. In particular, when the excitation frequency decreases, e.g., from F_2 to F_1, the value of the output signal increases, e.g., from V_{SENSE1} to V_{SENSE2}. In other words, in some examples, lowering the excitation frequency may increase the output signal and thus the gain of a capacitive sensing system. Thus, the output signal may be considered a function of the excitation frequency. Adjustment of the excitation frequency may cause a change to the output signal. Further, as shown by curves **202** and **204**, at different acceleration, e.g., from x to y, the output signal, e.g., V_{SENSE2}, corresponds to different excitation frequencies, e.g., F_1 and F_3. Thus, acceleration may be considered a function of the output signal and excitation frequency. Accordingly, by determining the output signal and excitation frequency, the acceleration may be determined.

[0032] FIG. **3** is a block diagram illustrating an example capacitive sensing system in more detail, according to some examples. As shown in FIG. **3**, capacitive sensing system **300** may include capacitive sensor **302** and sensing circuit **314**. In some examples, capacitive sensor **302** may be similar to capacitive sensor **102** described above in FIG. **1**. For example, capacitive sensor **302** may include a first capacitance (e.g., capacitance of top capacitor C**1 110**), e.g., between a first input terminal and an output terminal, and a second capacitance (e.g., capacitance of bottom capacitor C**2 112**), e.g., between the output terminal and a second input terminal.

[0033] In some examples, sensing circuit **314** may be similar to sensing circuit **114** described above in FIG. **1**. For example, as shown in FIG. **3**, sensing circuit **314** may also include excitation circuit **316** (similar to excitation circuit **116**), monitoring circuit **318** (similar to monitoring circuit **118**), and control circuit **320** (similar to control circuit **120**). In some examples, excitation circuit **316** may include controllable oscillating circuit **352**, which may generate first excitation signal $V_{\Phi 1}$ **322** of a first signal and second excitation signal $V_{\Phi 2}$ **324** of a second signal. For example, controllable oscillating circuit **352** may include an oscillator and a divisor. The oscillator may generate a clock signal at a constant frequency, and the divisor may have a controllably variable value. Controllable oscillating circuit **352** may divide the clock signal by the divisor to generate a divided clock signal, and generate $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324** based on the divided clock signal. Thus, by varying the value of the divisor, controllable oscillating circuit **352** may vary the frequencies of $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324**. In another example, controllable oscillating circuit **352** may include a relaxation oscillating circuit configured to generate $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324**, where the frequencies of $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324** may depend on values of a set of resistors of the relaxation oscillating circuit. Thus, controllable oscillating circuit **352** may adjust the frequencies of $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324** by varying the values of the resistors. In some examples, excitation circuit **316** may provide $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324** to capacitive sensor **302**, which may in response generate output signal V_{sense} **326**. In some examples, $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324** may have the same frequency and amplitude, and $V_{\Phi 1}$ **322** may be phase shifted relative to $V_{\Phi 2}$ **324**. In some examples, the phase shift may be 180 degrees, or in other words, $V_{\Phi 1}$ **322** may be out of phase relative to $V_{\Phi 2}$ **324**. Alternatively, in some examples, $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324** may have different frequencies and/or amplitudes, and the phase shift may be different from 180 degrees.

[0034] As shown in FIG. **3**, in some examples, monitoring circuit **318** may include inverting amplification circuit **340**, sampling circuit **342**, and comparison circuit **344**. In some examples, monitoring circuit **318** may optionally (as shown by the dashed lines) include digital-to-analog converter (DAC) **348**. As the name implies, in some examples, inverting amplification circuit **340** may receive output signal V_{sense} **326** and generate output signal V_{OTA} **360**, which may be an amplified version of V_{sense} **326** with an opposite phase. Note that FIG. **3** is provided only as an example for purposes of illustration. In some examples, monitoring circuit **318** may use a non-inverting amplification circuit, which may amplify V_{sense} **326** without the phase opposite. As shown in FIG. **3**, in some examples, sampling circuit **342** may receive output signal V_{OTA} **360** from inverting amplification circuit **340** and generate a sample of V_{OTA} **360**, e.g., $V_{S/H}$ **362**, during each sampling period. In some examples, comparison circuit **344** may receive $V_{S/H}$ **362** and a reference signal V_{REF} **366**, and generate signal V_{CF} **364** based on comparison between $V_{S/H}$ **362** and V_{REF} **366**. In some examples, V_{CF} **364** may indicate which one of $V_{S/H}$ **362** and V_{REF} **366** is larger. For example, in some examples, V_{CF} **364** may have a binary value, where one binary value (e.g., a binary one) indicates that $V_{S/H}$ **362** is not less than V_{REF} **366** and the other binary value (e.g., a binary zero) indicates that $V_{S/H}$ **362** is less than V_{REF} **366**. For purposes of illustration, comparison circuit **344** may be considered "triggered" when $V_{S/H}$ **362** is not less than V_{REF} **366**, and "untriggered" when $V_{S/H}$ **362** is less than V_{REF} **366**. As shown in FIG. **3**, in some examples, V_{REF} **366** may have a constant value, e.g., provided by a given voltage source. Alternatively, in some examples, V_{REF} **366** may be provided by DAC **348**, which may be varied by control circuit **320** (as described below).

[0035] Referring back to FIG. **3**, in some examples, control circuit **320** may include tracking circuit **350**. In some examples, tracking circuit **350** may receive V_{CF} **364**, and based on V_{CF} **364**, control the frequencies of $V_{\Phi 1}$ **322** and/or $V_{\Phi 2}$ **324** to determine the value of V_{sense} **326**. For example, as described above, V_{CF} **364** may be generated based on comparison between $V_{S/H}$ **362** (which represents V_{sense} **326**) and V_{REF} **366**. Further, as described above in FIG. **2**, V_{sense} **326** may be changed by adjustment of the frequencies of $V_{\Phi 1}$ **322** and/or $V_{\Phi 2}$ **324**. Thus, based on V_{CF} **364**, tracking circuit **350** may control the frequencies of $V_{\Phi 1}$ **322** and/or $V_{\Phi 2}$ **324** to search for the closest excitation frequencies that cause capacitive sensor **302** to generate V_{sense} **326** of the same value as V_{REF} **366**. Since the value of V_{REF} **366** is known to tracking circuit **350**, at conclusion of the search, tracking circuit **350** may accordingly determine the value of V_{sense} **326** and the corresponding excitation frequencies.

[0036] For example, referring to FIGS. **2** and **3**, consider that capacitive sensing system **300** operates at the acceleration of x, and V_{REF} **366** has a value between V_{SENSE1} and V_{SENSE2} corresponding to an excitation frequency F_4 (assuming $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324** have the same frequency). Additionally, to simplify explanation, consider that V_{SENSE} **326** is not amplified (e.g., $V_{S/H}$ **362** is equal to V_{SENSE} **326** directly). At beginning, excitation circuit **316** may generate $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324** at the frequency F_2. In response, capacitive sensor **302** may generate V_{sense} **326** of value V_{SENSE1}. As shown in FIG. **2**, V_{SENSE1} is less than V_{REF} **366**. Thus, comparison circuit **344** may be untriggered (indicated by V_{CF} **364**). Since comparison circuit **344** is untriggered, tracking circuit **350** may determine that V_{sense} **326** is less than V_{REF} **366**.

[0037] Next, control excitation circuit **316** may lower the frequency of $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324** from F_2 to F_1 to trigger comparison circuit **344**. As described above, in some examples, lowering the frequency of $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324** may increase output signal V_{sense} **326**. Thus, V_{sense} **326** may increase from V_{SENSE1} (at F_2) to V_{SENSE2} (at F_1). Because V_{SENSE2} is larger than V_{REF} **366**, comparison circuit **364** may be triggered (also indicated by V_{CF} **364**). Accordingly, tracking circuit **350** may determine that V_{sense} **326** is no less than V_{REF} **366**.

[0038] Next, tracking circuit **350** may adjust the frequency of $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324** in the opposite direction to untrigger comparison circuit **344**. For example, tracking circuit **350** may increase (e.g., step by step) the frequency of $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324** from F_1 until comparison circuit **344** is re-untriggered at frequency F_5. Thus, compared to F_1, F_5 is less than F_1 and thus closer to F_4 (the excitation frequency corresponding to V_{REF} **366**) than F_1.

[0039] Next, tracking circuit **350** may reverse the adjustment direction once again to decrease (e.g., step by step) the frequency of $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324** from F_5, until comparison circuit **344** is re-triggered at frequency F_6. Similarly, F_6 is a frequency closer to F_4 than F_2.

[0040] In some examples, tracking circuit **350** may repeat the above searching process. Depending on the step change or resolution of adjustment of the frequency of $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324**, tracking circuit **350** may or may not be able to settle at exactly the frequency F_4. Regardless, tracking circuit **350** may be able to identify an excitation frequency that is closest to F_4 amongst the controllably available frequency of $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324**. Even though described for the acceleration of x, the above operation applies to measurement at different acceleration. As described above in FIG. **2**, at different acceleration, the acceleration may be considered a function of output signal and excitation frequency. Thus, when values of output signal and excitation frequency are determined, the value of acceleration may be determined. For examples, in some examples, tracking circuit **350** may include a lookup table indicating the value of acceleration corresponding to different V_{sense} and excitation frequencies. Thus, once values of V_{sense} **326** and excitation frequency are determined, tracking circuit **3530** may access the lookup table to determine the corresponding acceleration.

[0041] Referring back to FIG. **3**, in some examples, tracking circuit **350** may generate δ_1 **330** to represent values or changes to values of the frequencies of $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324**. As described above, in some examples, controllable oscillating circuit **352** (of excitation circuit **116**) may use a divided clock signal to generate $V_{\Phi 1}$ **322** and $V_{\Phi 2}$ **324**. Thus, in that case, δ_1 **330** may indicate a value or change to the value of the divisor. In another example, controllable oscillating circuit **352** may use a relaxation oscillating circuit to generate $V_{\Phi1}$ **322** and $V_{\Phi2}$ **324**, where the frequencies of the $V_{\Phi1}$ **322** and $V_{\Phi2}$ **324** may depend on values of a set of resistors. Accordingly, in that case, δ_1 **330** may indicate a value or change to the value of at least one of the resistors.

[0042] As shown in FIG. **3**, in some examples, monitoring circuit **318** may optionally (as shown by the dashed lines) include DAC **348**. In some examples, DAC **348** may receive δ_1 **330** from tracking circuit **350**, and based on δ_1 **330**, generate the reference signal V_{REF} **366**. Inclusion of DAC **348** may expedite convergence of the above described searching process to the closest excitation frequency, thus further improving performance of capacitive sensing system **314**. For example, when tracking circuit **350** determines that comparison circuit **344** is untriggered (e.g., when V_{SENSE} **326** is less than V_{REF} **366**), tracking circuit **350** may use DAC **348** to lower the value of V_{REF} **366** (e.g., by lowering the frequency represented by δ_1 **330**) to accelerate triggering of comparison circuit **344**. Conversely, when comparison circuit **344** is triggered, tracking circuit **350** may use DAC **348** to increase the value of V_{REF} **366** (e.g., by increasing the frequency represented by δ_1 **330**) to speed up untriggering of comparison circuit **344**. Controllability of V_{REF} **366** may create one more control freedom to result in expedited determination of values of V_{SENSE} **326** and/or acceleration.

[0043] As shown in FIG. **3**, in some examples, tracking circuit **350** may generate signal δ_2 **332**. As described above, for example, for a capacitive accelerometer, tracking circuit **350** may determine a value of acceleration. Thus, δ_2 **332** may be a digital signal representing the determined value of acceleration. In some examples, control circuit **320** may provide δ_2 **332** to a processor (not shown), which may implement other functions such as automotive airbags, navigation, and instrumentation. In some examples, the processor or control circuit **320** may identify an "optimal" frequency to operate capacitive sensor **302**.

[0044] Note that FIG. **3** is provided only as an example for purposes of illustration. In some examples, tracking circuit **350** may use a variety of searching algorithm to look for the closest excitation frequency. For example, in some examples, tracking circuit **350** may adjust the frequency according to sequential searching (e.g., adjusting the frequency according to a predetermined sequence), successive approximation searching (e.g., adjusting the frequency based on the comparison result), delta-sigma, etc.

[0045] FIG. **4** is a block diagram illustrating an example monitoring circuit, according to some examples. As shown in FIG. **4**, in some examples, monitoring circuit **400** may be similar to the monitoring circuits described above in FIGS. **1-3**. For example, in some examples, monitoring circuit **400** may include low pass filter (LPF) **440**, inverting amplifier **472**, sampling circuit **442**, and comparator **444**. In some examples, LPF **440** may be formed by a resistor-capacitor (RC) circuit of R_{LPF} and C_{LPF}. LPF **440** may receive an output signal V_{sense} **426** from a capacitive sensor at an input terminal, and generate filtered output signal V_{sense} **426** at an output terminal. In some examples, inverting amplifier **472** may include an operational amplifier, an input capacitor C_{IN}, and a feedback capacitor C_{FB}. C_{IN} may be coupled to a negative (or inverting) input terminal of the operational amplifier, whereas C_{FB} may be coupled between the negative (or inverting) input terminal and an output terminal of the operational amplifier. In some examples, a common mode voltage V_{CM} (e.g., a DC voltage) may be provided to bias a positive (or non-inverting) input terminal of the operational amplifier and establish a DC operating point centered around the common mode voltage V_{CM}. For example, if the supply voltage of the operational amplifier is 1.5 V, the common mode voltage V_{CM} may be chosen as 800 mV to ensure sufficient and approximately equal room for voltages swings in either direction between 1.5 V and 0 V. This may provide the maximum readable range of V_{SENSE} **326**. As shown in FIG. **4**, LPF **440** may receive V_{sense} **426**, filter out high frequency components, and generate filtered output signal V_{sense} **426**. The filtered output signal V_{sense} **426** may be provided to the negative (or inverting) input terminal of the operational amplifier via input capacitor C_{IN}, and output signal V_{OTA} **460** (representing an amplified version of V_{sense} **426** with an opposite phase) may be generated at the output terminal of the operational amplifier. In some examples, input capacitor C_{IN} may provide AC coupling to the operational amplifier, thus increasing the input impedance of monitoring circuit **400** and reducing the capacitive sensing system's leakage current. This may help to achieve a lower power consumption especially at idle.

[0046] In some examples, sampling circuit **442** may include an input terminal and an output terminal. As shown in FIG. **4**, sampling circuit **442** may receive output signal V_{OTA} **460** from inverting amplifier **472** at the input terminal of sampling circuit **442**. In some examples, sampling circuit **442** may include a n-channel MOSFET (NFET) and a p-channel MOSFET (PFET) coupled between the input and output terminals of sampling circuit **442**. The output terminal may further be coupled to a capacitor $C_{S/H}$. The NFET and PFET may respectively be controlled by their gate signals to turn on and thus connect the output terminal to V_{OTA} **460** of the input terminal. The capacitor $C_{S/H}$ may hold $V_{S/H}$ **462** to the levels of V_{OTA} **460** that the NFET or PFET passes through.

[0047] In some examples, comparator **444** may include a positive input terminal, a negative input terminal, and an output terminal. As shown in FIG. **4**, in some examples, comparator **444** may receive $V_{S/H}$ **462** at the positive input terminal, and reference signal V_{REF} **466** at the negative input terminal, and generate signal V_{CF} **464** at the output terminal. As described above, V_{CF} **464** may be provided to a tracking circuit of a control circuit (e.g., tracking circuit **350** of control circuit **320** in FIG. **3**). Further, in some examples, V_{REF} **466** may have a constant value, e.g., provided by a given voltage source. Alternatively, in some examples, V_{REF} **466** may be generated by a DAC (e.g., DAC **348**) under control of the tracking circuit.

[0048] FIG. **5** is a diagram illustrating an example relationship between output signal and acceleration of a capacitive sensor, according to some examples. As shown in FIG. **5**, waveforms **502** and **504** illustrate an output signal V_{sense} of a capacitive sensor in response to excitation signals at acceleration of respectively different directions. As shown by waveform **502**, output signal V_{sense} increases when the acceleration increases from 0 g to 1 g and 2 g in a first direction, where 1 g equals to 9.8 m/s^2. As shown in FIG. **5**, waveform **502** may include rising edge **504** at beginning. In some examples, a sampling circuit (e.g., the sampling circuits described above in FIGS. **3-4**) may sample positive peaks **510**, **512**, **514**, etc. of output voltage V_{sense}. By comparison, waveform **504** illustrates output signal V_{sense} when acceleration is in a second direction opposite to the first direction of waveform **502**. As shown in FIG. **5**, while V_{sense} also increases with the acceleration (e.g., from 0 g to

−1 g and −2 g), waveform **504** may include falling edge **508** at beginning. At the same points in time, the sampling circuit may sample negative peaks **520**, **522**, **524**, etc. of output voltage V_{sense}. Thus, based on the samples (especially the sign of the samples) of output signal V_{sense}, a direction of the acceleration may be determined.

[0049] FIG. **6** is a block diagram illustrating an example excitation circuit, according to some examples. As shown in FIG. **6**, in some examples, excitation circuit **600** may include a relaxation oscillating circuit configured to generate first voltage signal $V_{\Phi 1}$ **622** and second voltage signal $V_{\Phi 2}$ **624**. In some examples, the frequencies of $V_{\Phi 1}$ **622** and $V_{\Phi 2}$ **624** may depend on at least resistors R_1 **680**, R_2 **682**, and R_3 **684**. For example, adjustment of resistors R_1 **680**, R_2 **682**, and R_3 **684** change the gate voltages of PFETs **688** and **690**, which in turn may affect charging and discharging of the two capacitors C **686**. The charging and discharging of capacitors C **686** may further generate $V_{\Phi 1}$ **622** and $V_{\Phi 2}$ **624**. In some examples, $V_{\Phi 1}$ **622** and $V_{\Phi 2}$ **624** may have the same frequency, and the two signals may be out of phase (e.g., a phase shift of 180 degrees) relative to each other. In some examples, the frequency of $V_{\Phi 1}$ **622** and $V_{\Phi 2}$ **624** may be determined by resistors R_1 **680**, R_2 **682**, R_3 **684**, and capacitors C **686** according to the equation

$$f = \frac{R_2}{C(R_2 + R_1)R_3}.$$

Thus, by adjusting at least one of resistors R_1 **680**, R_2 **682**, and R_3 **684**, the frequency of $V_{\Phi 1}$ **622** and $V_{\Phi 2}$ **624** may be controlled. For example, in some examples, R_2 **682** may be a variable resistor, and by increasing the value of R_2 **682**, the frequency of $V_{\Phi 1}$ **622** and $V_{\Phi 2}$ **624** may be reduced. As described above, in some examples, this may increase the gain of a capacitive sensing system. In some examples, R_2 **682** and R_3 **684** may be part of one integrated resistor (e.g., a potentiometer), such that the summation of R_2 **682** and R_3 **684** is a constant but the ratio between R_2 **682** and R_3 **684** is variable.

[0050] Note that FIG. **6** is provided only as an example for purposes of illustration. In some examples, excitation circuit **600** may use a variety of circuits to generate $V_{\Phi 1}$ **622** and $V_{\Phi 2}$ **624**. For example, in some examples, excitation circuit **600** may include an oscillator and a divisor. Excitation circuit **600** may divide a clock signal (at a constant frequency) from the oscillator by the divisor to generate a divided clock signal, and generate $V_{\Phi 1}$ **622** and $V_{\Phi 2}$ **624** based on the divided clock signal. In that case, the frequencies of $V_{\Phi 1}$ **622** and $V_{\Phi 2}$ **624** may be adjusted by controlling a value of the divisor.

[0051] FIG. **7** is a flowchart illustrating an example method for performing sensing based on a capacitive sensor, according to some examples. As shown in FIG. **7**, in some examples, a first signal of a first frequency and a second signal of a second frequency may be provided to a capacitive sensor to generate a third signal, as indicated by block **702**. As described above, in some examples, the first and second signals may be excitation voltages generated by an excitation circuit of a sensing circuit of a capacitive sensing system. In some examples, the first frequency may be equal to the second frequency. Further, in some examples, the first signal may have a phase shift relative to the second signal. In some examples, the phase shift may be 180 degrees, or in other words, the first signal may be out of phase relative to the second signal.

[0052] As shown in FIG. **7**, in some examples, the third signal from the capacitive sensor may be received, e.g., as indicated by block **704**. As described above, in some examples, the third signal may be received by a monitoring circuit of the sensing circuit. In some examples, the monitoring circuit may generate an output signal based on the third signal. For example, the monitoring circuit may compare a signal representing the third signal (e.g., samples representing the third signal) with a reference signal to generate the output signal.

[0053] As shown in FIG. **7**, in some examples, the first frequency of the first signal and/or the second frequency of the second signal may be controlled to determine a value of the third voltage, as indicated by block **706**. As described above, the output signal from the monitoring circuit may be received by a control circuit of the sensing circuit. Based on the output signal, the control circuit may adjust the first frequency and/or the second frequency (iteratively) to search for the closest excitation frequencies. At conclusion of the adjustment, the control circuit may determine the value of the third signal based on a value of the reference signal.

[0054] FIG. **8** is a flowchart illustrating an example method for performing sensing of acceleration based on a capacitive sensor, according to some examples. As shown in FIG. **8**, in some examples, a first signal of a first frequency and a second signal of a second frequency may be provided to a capacitive sensor to generate a third signal, as indicated by block **802**. In some examples, the first frequency and/or the second frequency may be adjusted to cause a change to the third signal, as indicated by block **804**. As described above, in some examples, decreasing the first frequency and/or the second frequency may increase the third signal, whereas increasing the first frequency and/or the second frequency may decrease the third signal. Further, when acceleration changes, one value of the third signal may correspond to different first and/or second frequencies. In some examples, an output signal or a result may be generated based on the third signal and a reference signal, as indicated by block **806**. For example, as described above, in some examples, the output signal may be generated based on comparison between the third signal and the reference signal. In some examples, it may be determined whether to conclude the adjustment of the first and/or second signal based on monitoring of the output signal, as indicated by block **808**. For example, as described above, in some examples, based on the output signal, an iterative frequency adjustment may be performed to identify the closest first and/or second frequency for the capacitive sensor to generate the third signal of the same value as the reference signal. In some examples, in response to determining to conclude the frequency adjustment, values of the third signal, the first frequency, and/or the second frequency may be determined, as indicated by block **810**. For examples, as described above, the value of the third signal may be determined based on a value of the reference signal, whereas the values of the first and/or second frequencies may be determined based on the above concluded frequency adjustment. In some examples, a value of acceleration may be determined based on the determined values of the third signal, the first frequency, and/or the second frequency, as indicated by block **812**. For examples, as described above, a lookup table may indicate the value of acceleration corresponding to different values of the third signal, the first frequency, and/or the second frequency. Thus, based on the lookup table, the value of acceleration may be determined from the values of the third signal, the first frequency, and/or the second frequency.

[0055] As used herein, the term "circuit" can include a collection of active and/or passive elements that perform a circuit function, such as an analog circuit or control circuit. Additionally or alternatively, for example, the term "circuit" can include an integrated circuit (IC) where all and/or some of the circuit elements are fabricated on a common substrate (e.g., semiconductor substrate).

[0056] The control circuit described herein (e.g., control circuit **320**) can be implemented as generic or custom processors (e.g., coupled to a memory) and configured to execution instructions stored in such memory. For example, the processors can include one or more, generic or custom, integrated circuits (ICs) (e.g., application-specific integrated circuits (ASICs)), logic circuits, microprocessors, field programmable gate arrays (FPGAs) that may instantiate instructions, central processor units (CPUs), graphic processor units (GPUs), digital signal processors (DSPs), or controllers. In some examples, the processors can include dedicated or general purpose circuitry, and the various processors may be combined or discrete circuitry.

[0057] In this description, the term "couple" may cover connections, communications, or signal paths that enable a functional relationship consistent with this description. For example, if device A generates a signal to control device B to perform an action: (a) in a first example, device A is coupled to device B by direct connection; or (b) in a second example, device A is coupled to device B through intervening component C if intervening component C does not alter the functional relationship between device A and device B, such that device B is controlled by device A via the control signal generated by device A.

[0058] Also, in this description, the recitation "based on" means "based at least in part on." Therefore, if X is based on Y, then X may be a function of Y and any number of other factors.

[0059] A device that is "configured to" perform a task or function may be configured (e.g., programmed and/or hardwired) at a time of manufacturing by a manufacturer to perform the function and/or may be configurable (or reconfigurable) by a user after manufacturing to perform the function and/or other additional or alternative functions. The configuring may be through firmware and/or software programming of the device, through a construction and/or layout of hardware components and interconnections of the device, or a combination thereof.

[0060] As used herein, the terms "terminal", "node", "interconnection", "pin" and "lead" are used interchangeably. Unless specifically stated to the contrary, these terms are generally used to mean an interconnection between or a terminus of a device element, a circuit element, an integrated circuit, a device or other electronics or semiconductor component.

[0061] While the use of particular transistors are described herein, other transistors (or equivalent devices) may be used instead with little or no change to the remaining circuitry. For example, a field effect transistor ("FET") (such as an n-channel FET (NFET) or a p-channel FET (PFET)), a bipolar junction transistor (BJT—e.g., NPN transistor or PNP transistor), insulated gate bipolar transistors (IGBTs), and/or junction field effect transistor (JFET) may be used in place of or in conjunction with the devices disclosed herein. The transistors may be depletion mode devices, drain-extended devices, enhancement mode devices, natural transistors or other types of device structure transistors. Furthermore, the devices may be implemented in/over a silicon substrate (Si), a silicon carbide substrate (SiC), a gallium nitride substrate (GaN) or a gallium arsenide substrate (GaAs).

[0062] Circuits described herein are reconfigurable to include additional or different components to provide functionality at least partially similar to functionality available prior to the component replacement. Components shown as resistors, unless otherwise stated, are generally representative of any one or more elements coupled in series and/or parallel to provide an amount of impedance represented by the resistor shown. For example, a resistor or capacitor shown and described herein as a single component may instead be multiple resistors or capacitors, respectively, coupled in parallel between the same nodes. For example, a resistor or capacitor shown and described herein as a single component may instead be multiple resistors or capacitors, respectively, coupled in series between the same two nodes as the single resistor or capacitor.

[0063] While certain elements of the described examples are included in an integrated circuit and other elements are external to the integrated circuit, in other example embodiments, additional or fewer features may be incorporated into the integrated circuit. In addition, some or all of the features illustrated as being external to the integrated circuit may be included in the integrated circuit and/or some features illustrated as being internal to the integrated circuit may be incorporated outside of the integrated. As used herein, the term "integrated circuit" means one or more circuits that are: (i) incorporated in/over a semiconductor substrate; (ii) incorporated in a single semiconductor package; (iii) incorporated into the same module; and/or (iv) incorporated in/on the same printed circuit board.

[0064] Uses of the phrase "ground" in the foregoing description include a chassis ground, an Earth ground, a floating ground, a virtual ground, a digital ground, a common ground, and/or any other form of ground connection applicable to, or suitable for, the teachings of this description. In this description, unless otherwise stated, "about," "approximately" or "substantially" preceding a parameter means being within +/−10 percent of that parameter.

[0065] While the foregoing is directed to specific examples, other and further examples may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. A device, comprising:

an excitation circuit having a first output terminal and a second output terminal, the first output terminal configured to provide a first signal of a first frequency to a capacitive sensor, the second output terminal configured to provide a second signal of a second frequency to the capacitive sensor;

a monitoring circuit having an input terminal configured to receive a third signal from the capacitive sensor in response to the first and second signals; and a control circuit configured to control the first frequency of the first signal and the second frequency of the second frequency to determine a value of the third signal.

2. The device of claim **1**, wherein the monitoring circuit comprises a sampling circuit having an input terminal and an output terminal, the output terminal configured to provide an output signal representing the third signal.

3. The device of claim **2**, wherein the monitoring circuit comprises an amplification circuit having an input terminal and an output terminal, the output terminal coupled to the input terminal of the sampling circuit.

4. The device of claim **3**, wherein the amplification circuit comprises a first capacitor, a second capacitor, and an operational amplifier having a first input terminal, a second input terminal, and an output terminal, the first capacitor coupled between the input terminal of the amplification circuit and the first input terminal of the operational amplifier, the second capacitor coupled between the first input terminal of the operational amplifier and the output terminal of the operational amplifier, and the output terminal of the operational amplifier coupled to the output terminal of the amplification circuit.

5. The device of claim **4**, wherein the second input terminal of the operational amplifier is configured to receive an input voltage.

6. The device of claim **3**, wherein the monitoring circuit comprises a low pass filter (LPF) having a first terminal and a second terminal, the first terminal configured to receive the third signal of the capacitive sensor, the second terminal coupled to the input terminal of the amplification circuit.

7. The device of claim **2**, wherein the monitoring circuit comprises a comparison circuit configured to provide an output signal based on between the output signal of the sampling circuit and a reference signal.

8. The device of claim **7**, wherein the comparison circuit comprises a comparator having a first input terminal, a second input terminal, and an output terminal, the first input terminal coupled to the output terminal of the sampling circuit, the second input terminal configured to receive the reference signal, and the output terminal configured to provide the output signal.

9. The device of claim **7**, wherein the control circuit comprises a tracking circuit configured to determine the value of the third signal based on the reference signal and the output signal of the comparison circuit.

10. The device of claim **9**, wherein to determine the value of the third signal, the tracking circuit is configured to:

adjust the first frequency of the first signal and the second frequency of the second signal;

determine whether to conclude adjustment of the first frequency and the second frequency based on the output signal of the comparison circuit; and

based on determining to conclude the adjustment, determine the value of the third signal based on a value of the reference signal.

11. The device of claim **10**, wherein the control circuit is configured to determine a value of acceleration based on the value of the third signal, the first frequency, and the second frequency.

12. The device of claim **11**, wherein the capacitive sensor is a capacitive accelerometer, and wherein the device is associated with a tire pressure monitoring system (TPMS).

13. The device of claim **1**, wherein the first signal is a first pulse-shaped signal, and the second signal is a second pulse-shaped signal, wherein the first frequency is equal to the second frequency, and wherein the first pulse-shaped signal is out of phase relative to the second pulse-shaped signal.

14. The device of claim **1**, wherein the capacitive sensor comprises a first capacitance between a first terminal and a third terminal, and a second capacitance between the third terminal and a second terminal, the first terminal coupled to the first output terminal of the excitation circuit, the second terminal coupled to the second output terminal of the excitation circuit, and the third terminal coupled to an input terminal of the monitoring circuit.

15. A method, comprising:

providing a first signal of a first frequency and a second signal of a second frequency to a capacitive sensor to generate a third signal;

receiving the third signal from the capacitive sensor; and

controlling the first frequency of the first signal and the second frequency of the second signal to determine a value of the third signal.

16. The method of claim **15**, comprising:

generating a sample based on the third signal; and

comparing the sample with a value of a reference signal to generate a comparison result.

17. The method of claim **16**, wherein controlling the first frequency of the first signal and the second frequency of the second signal to determine a value of the third signal comprises:

adjusting the first frequency of the first signal and the second frequency of the second signal to cause a change to the third signal;

determining whether to conclude adjustment of the first frequency and the second frequency based on the comparison result; and

based on determining to conclude the adjustment, determine the value of the third signal based on the value of the reference signal.

18. The method of claim **17**, further comprising:

determining a value of acceleration based on the determined value of the third signal, the first frequency, and the second frequency.

19. The method of claim **18**, the capacitive sensor is a capacitive accelerometer of a tire pressure management system (TPMS).

20. The method of claim **15**, wherein the first signal is a first sinusoidal signal, and the second signal is a second sinusoidal signal, wherein the first frequency is equal to the second frequency, and wherein the first sinusoidal signal is out of phase relative to the second sinusoidal signal.

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