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(54) INDUCTIVE SENSING WITH DIFFERENTIAL INDUCTANCE READOUT BASED ON SENSE/REFERENCE LC-RING OSCILLATORS WITH A SHARED CAPACITOR

INDUKTIVE MESSUNG MIT ABLESUNG DER DIFFERENZIELLEN INDUKTIVITÄT AUF DER BASIS VON SENSOR-/REFERENZ-LC-RINGOSZILLATOREN MIT GEMEINSAMEM KONDENSATOR

DÉTECTION INDUCTIVE À LECTURE D’INDUCTANCE DIFFÉRENTIELLE SUR LA BASE D’OSCILLATEURS EN ANNEAU LC DE DÉTECTION/RÉFÉRENCE AVEC UN CONDENSATEUR PARTAGÉ

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Description

[0001] This relates generally to inductive sensing, and more particularly to resonant inductive sensing.

BACKGROUND

[0002] Inductive sensors are used to detect/measure events/conditions based on changes in a sensing B-field. The inductive sensor includes a sense inductor coil, coupled to an inductance-to-data converter (IDC). The IDC drives the sensor coil to project the sensing B-field, and acquires sensor measurements (readout) corresponding to changes in the projected B-field, which correspond to the sensed event/condition.

[0003] For example, inductive proximity sensor/switches detect the proximity of a conductive target to the inductive sensor, within a defined proximity switching threshold. Inductive proximity sensors/switches have sufficient dynamic range to detect proximity with nanometer resolution. However, switching accuracy is limited by temperature drift and component tolerances.

[0004] Inductive sensing, including inductive proximity sensing, can be implemented based on resonant sensing in which the inductive sensor is a resonator with a inductor coil and a series/parallel capacitor (LC tank circuit), with losses in the sensor resonator characterized by a series resistance Rs (loss factor). The IDC drives the sensor resonator to maintain a resonance state (sustained oscillation), projecting a sensing B-field, and acquires sensor measurements corresponding to sensor response to a proximate target as reflected in changes in the resonance state of the sensor resonator.

[0005] Sensor resonator response manifested as changes in resonance state can be based on either: (a) measuring changes in sensor resonator losses due to eddy current losses in the target (eddy current sensing), manifested as a change in sensor resonator impedance; or (b) measuring a change in sense coil inductance due to eddy current back emf, manifested as a change in sensor resonator oscillation frequency. In the case of resonator losses, the resonator loss factor Rs can be characterized by an equivalent parallel impedance Rp (Rp = (1/Rs)*(L/C)), which takes into account frequency-dependent LC reactive impedance, so that changes in total resonator impedance 1/Rp can be measured as a change in the negative impedance -1/Rp required to counterbalance resonator impedance and maintain resonance (sustained oscillation). In the case of resonator inductance, back emf caused by the induced eddy currents effectively changes sensor coil inductance, manifested as a corresponding change in resonator oscillation frequency required to maintain resonance (sustained oscillation). Design considerations include required sensitivity and tolerance for temperature effect. For example, eddy current sensing based on sensor resonator losses is more sensitive, but sensor inductance is less susceptible to temperature effects.

[0006] In at least one example, for two identical sensor resonators used in a multi-channel configuration with a single IDC, even if resonator capacitor mismatch is reduced to 0.1% for both LC tanks, the resulting distance error can be 1% of coil diameter. EP 0371261 relates to a method for inductively generating electric measuring signals for determining the park/position/material properties of a test sample, proximity sensor constructed according to the method and its use as a proximity switch.

SUMMARY

[0007] Described examples include apparatus and methods for inductive sensing with differential inductance readout based on sense/reference LC-ring oscillators with a shared resonator capacitor, such as can be used for inductive proximity sensing/switching.

[0008] In described examples, the inductive sensing methodology is suitable for use with sense/reference resonators, the Lsense/Lref resonators including sense/reference inductor coils LS/LR, and including a common (shared) resonator capacitor Cc. The methodology includes: (a) driving the Lsense resonator as a time-multiplexed Lsense ring oscillator, including driving time-multiplexed Lsense resonator excitation signals into the Lsense resonator, to maintain Lsense resonator oscillation, based on resulting time-multiplexed Lsense resonance measurements input to the Lsense ring oscillator from the Lsense resonator; and (b) driving the Lref resonator as a time-multiplexed Lref ring oscillator, including driving time-multiplexed Lref resonator excitation signals into the Lref resonator, to maintain Lsense resonator oscillation, based on resulting time-multiplexed Lref resonance measurements input to the Lref ring oscillator from the Lref resonator; and (c) time-multiplexing the operation of the Lsense and Lref ring oscillators to enable sharing the common resonator capacitor Cc by the Lsense and Lref resonators. Differential readout data is provided based on the time-multiplexed Lsense and Lref resonance measurements, corresponding respectively to inductances of the LS and LR inductor coils.

[0009] In other aspects: (a) the Lsense resonance measurements correspond to a resonance state of the Lsense resonator, including a resonance state with steady-state oscillation, and the Lref resonance measurements correspond to a resonance state of the Lref resonator, including a resonance state with steady-state oscillation; (b) the differential readout data is based on Lsense and Lref resonator oscillation frequency, as related respectively to the inductances of the LS/LR inductor coils; (c) the LC-ring oscillators can be implemented with a Schmitt trigger coupled to the LCOM input to convert time-multiplexed Lsense/Lref resonance measurements, to digital Schmitt trigger output, based on predetermined high and low thresholds, provided to the Lsense/Lref drivers; and (d) parasitic capacitance can be suppressed by one of selectively shorting an inactive one of the inductor coils, or selectively bootstrapping a voltage from the common resonator capacitor Cc across an inactive one of the inductor coils.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

FIGS. 1A/1B illustrate an example embodiment of an inductive sensor 120 with differential inductance readout based on sense/reference LC-ring oscillators with a shared capacitor, including differential sense and reference resonators (LS/LR, Cc) driven by a Schmitt trigger 122 that converts analog resonance measurements from the resonators into digital resonator excitation signals driven out to the resonators by matched drivers 124, 126, which are enabled/disabled (OEsense/OEref) to time-multiplex (FIG. 1B, 124_OE, 126_OE) the sense/reference resonators (enabling operation with a shared capacitor).

FIGS. 2A/2B illustrates, for the example inductive sensor of FIG. 1A, an example LC-ring oscillator operation for the sense resonator (LS, Cc), including the relationship between the resonator oscillation frequency (125osc), and the Schmitt trigger levels (high/low), with the Schmitt trigger 122 converting resonance measurements 125c from the sense resonator to digital sense resonator excitation signals 122A.

FIG. 3 illustrates, for the example embodiment of an inductive sensor 120 using sense/reference LC-ring oscillators with a shared capacitor, the effect of parasitic capacitance (Cpar) on the sense/reference drivers 124, 126, including introducing a second resonance mode.

FIGS. 4 and 5 illustrate alternate example embodiments of an inductive sensor 120 using sense/reference LC-ring oscillators with a shared capacitor, including modifications to the sense/reference LC-ring oscillators to minimize the second resonance mode caused by parasitic capacitance (Cpar). FIG. 4 illustrates an example embodiment in which the LC-ring oscillators include shorting switches (Ssense, Sref) connected across the LS and LR inductor coils to selectively short the disabled resonator. FIG. 5 illustrates an example embodiment in which the LC-ring oscillators include shorting switches (Ssense, Sref) connected in series with respective bootstrap buffer amplifiers 535, 537, across the LS and LR inductor coils to selectively bootstrap the common capacitor voltage across the disabled resonator.

FIGS. 6A and 6B illustrate example embodiments of inductive sensor systems 600 providing differential inductance readout based on sense/reference LC-ring oscillators, including an IDC 601 coupled to sense/reference resonators, with LSENSE and LREF outputs coupled to LS and LR inductor coils, and an LCOM input coupled to a common (shared) resonator capacitor Cc, the IDC including a differential IDC core 621 with LC-ring oscillator converters for the sense/reference resonators to provide differential inductance readout for input to a digital Schmitt trigger 651 (LS+ and LR-).

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0011] Example embodiments are directed generally to inductive sensing for various applications, such as inductive proximity sensing. In at least one example, inductive sensing with differential inductance readout is based on sense/reference LC-Ring oscillators with a shared capacitor.

[0012] According to example embodiments, applications for inductive sensing include proximity switching based on a difference or ratio of the differential sense/reference inductance readout, and applications such as weight scales where a ratio of the differential sense/reference inductance readout can be used directly.

[0013] LC-ring oscillator refers to a ring (time-delay) oscillator in which an LC resonator is a delay element (in the example embodiments, the dominant delay element). Resonance measurements refer to measurements of the resonance state of an LC resonators, including a resonance state with steady-state oscillation, such as based on resonator oscillation frequency at resonance.

[0014] In brief overview, inductive sensing (such as for proximity switching) provides differential inductance readout based on Sense/Reference resonators implemented as LC-ring oscillators, with LS/LR inductor coils and a shared (time-multiplexed) resonator capacitor. The ring oscillators include matched Lsense/Lref drivers time-multiplexed (by out enable signals), to provide Lsense/Lref resonator excitation signals to the Lsense/Lref resonators, based on resulting Lsense/Lref resonance measurements (such as of resonance state) acquired by the ring oscillators from the Lsense/Lref resonators (establishing an LC-ring oscillator loop). Differential readout data is based on the time-multiplexed Lsense/Lref resonance measurements, corresponding respectively to LS/LR coil inductances (such as based on Lsense/Lref resonator oscillation frequency). The ring oscillators can be implemented with a Schmitt trigger, converting analog resonance measurements into digital input to the Lsense/Lref drivers. Driver matching and layout matching can be used to improve accuracy. Effects of parasitic capacitance at the driver outputs can be suppressed by shorting or bootstrapping across the inactive LS/LR coil inductances.

[0015] FIGS. 1A/1B illustrate an example embodiment of an inductive sensor 120 with differential inductance readout based on sense/reference LC-ring oscillators with a shared capacitor. Differential sense (Lsense) and reference (Lref) resonators (LS/LR, Cc) are coupled to an inductance-to-data converter (IDC) including an IDC core 121.

[0016] The Lsense/Lref resonators and IDC core 121 form dual, sense/reference LC-ring oscillators in which the Lsense/Lref resonators are time-multiplexed to enable resonator operation with a shared capacitor Cc.

[0017] The Lsense and Lref resonators include LS and LR inductor coils, each coupled to common (shared) capacitor Cc, forming dual LC tank circuits. As illustrated, the resonator inductor coils are represented by an inductor element 125 that includes sense inductor coil LS and a loss factor represented by resistor RS, and an inductor element 127 that includes reference inductor coil LS and a loss factor represented by resistor RR. Thus, the resonator inductor coils can be referenced by either LS/LR, or 125/127.

[0018] Using sense and reference inductor coils LS and LR eliminates temperature drift. However, accurate differential inductance readout requires matching the LS and LR sensor inputs (measurements). Using sense/reference LC-ring oscillators with time-multiplexed Lsense/Lref resonators enables resonator operation with a shared capacitor, eliminating the need for accurately matched separate resonator capacitors. Moreover, LC-ring oscillators have a low noise floor, providing low phase jitter.

[0019] IDC core 121 drives the Lsense/Lref resonators as LC-ring oscillators using a Schmitt trigger 122 and matched Lsense and Lref inverting drivers 124, 126. Schmitt trigger 122 has an input coupled to the Lsense/Lref resonators at an LCOM input port coupled to common (shared) capacitor Cc, and an output coupled to the Lsense/Lref drivers 124, 126. Drivers 124/126 are coupled to respective Lsense/Lref resonators through LSENSE and LREF output ports, coupled to the LS and LR inductor coils.

[0020] Schmitt trigger 122 converts analog resonance measurements received from the Lsense/Lref resonators through the LCOM port, into digital Lsense/Lref resonator excitation signals. The matched Lsense/Lref inverting drivers 124, 126 drive the Lsense/Lref resonator excitation signals out of the LSENSE/LREF output ports to the resonators.

[0021] Lsense/Lref drivers 124, 126 are enabled/disabled by out enable signals OEsense/OEref to time-multiplex the Lsense/Lref resonator excitation signals, thereby time-multiplexing the Lsense/Lref resonators for operation with the shared capacitor Cc (see FIG. 1B, 124_OE, 126_OE). That is, when the inductance of the LS sense inductor coil is measured (Lsense resonance measurement input to the Schmitt trigger), only OEsense is active to enable the Lsense driver 124, while OEref is low, disabling Lref driver 126 (high output impedance). And, when the inductance of the LR reference inductor coil is measured (Lref resonance measurement input to the Schmitt trigger), only OEref is active to enable the Lref driver 124, while OEsense is low, disabling Lsense driver 126 (high output impedance).

[0022] In this time-multiplexing configuration for implementing the Lsense/Lref ring oscillators, Schmitt trigger 122 and the resonator capacitor Cc are shared. Mismatch between the Lsense/Lref drivers 124, 126 results in mismatch in propagation delay from Schmitt trigger input to the output, and mismatch in output impedance. Mismatch requirements for the delay can be relaxed under the condition that the delay is only a small fraction of the total oscillation period (for example, less than 2%). Mismatch in the output impedance can be relaxed if the input resistance of the drivers Rout < ωLs and Rout < ωLR, where ω = 6.28*resonator oscillation frequency.

[0023] Not that the analog Schmitt trigger 122 in the ring oscillator core is a design choice to provide noise immunity. For some application with reduced noise immunity requirements, the analog Schmitt trigger can be eliminated.

[0024] FIGS. 2A/2B illustrate, for the example inductive sensor of FIG. 1A, an example LC-ring oscillator operation for the Lsense (sense) resonator (LS, Cc). The sense-side LC-ring oscillator includes Schmitt trigger 122 and inverting driver 124.

[0025] Schmitt trigger 122 receives Lsense resonance measurements 125osc from the Lsense resonator (Ls/Cc) through the LCOM port coupled to the shared capacitor Cc. The Schmitt trigger converts the Lsense resonance measurements 125osc to digital Lsense resonator excitation signals 122A.

[0026] The actual oscillation mode for the Lsense resonator depends on the thresholds of the Schmitt trigger, relative to the levels of the Lsense resonator excitation signals output from the Lsense driver 124. FIG. 2B illustrates the relationship between resonator oscillation frequency 125osc (across the shared capacitor Cc), and the high/low Schmitt trigger levels used to generate the digital Lsense resonator excitation signals 122A. As soon as the input to Schmitt trigger 122 crosses threshold high level, the output of the buffer is driven low, and as soon as the input to Schmitt trigger 122 drops below the threshold low level, the output is driven high.

[0027] For example, the threshold high/low values can be set in relation to Vdd, such as a_high*Vdd and a_low*Vdd. Since the resonator oscillation signal across Cc is approximately the first harmonic of the square wave driving the resonator, and hence a sine wave, a_high and a low determine the phase difference between the square wave driving the sensor and the sine wave at the input of the Schmitt trigger. For a high = 2/3 and a_low = 1/3, the oscillation frequency is approximated by

$$Fosc \approx \sqrt{(2/L_S C_C)}(1 - R_S C_C)$$

[0028] Referring to FIG. 1A, differential inductance readout is based on LS and LR coil inductances, derived from the time-multiplexed Lsense/Lref resonance measurements for the Lsense/Lref resonators. For the example embodiment, IDC core 121 includes differential readout implemented as a differential frequency counter

141.

[0029] Frequency counter 141 is coupled to receive the differential, time-multiplexed Schmitt trigger digital output (FIG. 2B). The Schmitt trigger digital output is based on the time-multiplexed Lsense/Lref resonance measurements input to Schmitt trigger 122. The frequency of the Schmitt trigger digital output depends on resonator oscillation frequency, which is a function of LS/LR coil inductance.

[0030] While the example embodiment implements differential inductance readout derived from the differential (time-multiplexed) sense/reference LC-ring oscillators based on Lsense/Lref resonator oscillation frequency, other measures of LS/LR coil inductance can be used. For example, while sensor inductance can be measured as changes back emf caused by induced eddy currents, sensor inductance can also be measured as changes in sensor losses resulting from induced eddy current losses, and changes in total sensor impedance based on changes in sensor inductance and loss factor.

[0031] FIG. 3 illustrates, for the example embodiment of an inductive sensor 120 using sense/reference LC-ring oscillators, the effect of parasitic capacitance Cpar on the sense/reference drivers 124, 126, including introducing a second resonance mode.

[0032] As illustrated, the time-multiplex phase is reading LS coil inductance (for the Lsense resonator), and hence the Lsense driver 124 is enabled to drive resonator excitation signals to the Lsense resonator. As such, Lsense driver 124 has low output impedance, while the Lref driver is disabled, and has a high output impedance (which can be referred to as a high-Z).

[0033] Ideally only the Lsense resonator (LS Cc) is active, which is indicated by dashed line 125A through the LS inductor coil. The parasitic capacitance Cpar that is loading the enabled Lsense driver 124 has no impact on the resonator oscillation frequency, and therefore no impact on inductance readout, due to the low output impedance of this driver. However as indicated by dashed line 127A, the parasitic capacitor Cpar loading the disabled Lref driver 126 (high-Z) adds a second resonant mode through the inactive LR inductor coil. Similarly, when Lref driver 126 is enabled, and the Lsense driver 124 is disabled (high-Z), the parasitic capacitor Cpar loading the disabled Lsense driver driving the Lsense resonator causes a second resonance mode through the inactive Ls inductor coil. The second resonance mode is undesirable, since it can interfere with desired resonance mode.

[0034] FIGS. 4 and 5 illustrate alternate example embodiments of an inductive sensor 120, including modifications to the sense/reference LC-ring oscillators to minimize the second resonance mode caused by parasitic capacitance. To suppress the second resonant mode, these alternate embodiments prevent current flowing through the parasitic capacitor and inactive LS/LR inductor coil.

[0035] FIG. 4 illustrates an example embodiment in which the LC-ring oscillators include shorting switches Ssense, Sref connected across the LS and LR inductor coils to selectively short the inactive LS/LR inductor coil. If a matched layout is used, both parasitic capacitors are matched as well, and the accuracy of the differential inductance measurement is not affected. For this implementation, the parasitic capacitance Cpar is added to the resonator capacitance Cc.

[0036] FIG. 5 illustrates an example embodiment in which the LC-ring oscillators include shorting switches Ssense, Sref connected in series with respective bootstrap buffer amplifiers 535, 537, across the LS and LR inductor coils, to selectively bootstrap the common capacitor voltage across the disabled resonator. The bootstrap amplifiers can be as simple as a source follower or emitter follower. The advantage of this implementation is that any mismatch between the parasitic capacitors does not impact overall accuracy.

[0037] FIGS. 6A and 6B illustrate example embodiments of inductive sensor systems 600 for inductive proximity switching according to example embodiments.

[0038] An IDC 601 is coupled to sense/reference resonators, with LSENSE and LREF outputs respectively coupled to LS and LR inductor coils, and an LCOM input coupled to a common (shared) resonator capacitor Cc. For this example proximity switching application, IDC 601 provides proximity switching based on a difference (or ratio) of LS and LR coil inductance.

[0039] IDC 601 provides differential inductance readout based on sense/reference LC-ring oscillators, as described in connection with FIGS. 2A/2B. A differential IDC core 621 includes sense and reference LC-ring oscillator converters incorporating the sense/reference resonators (sense/reference LS/LR inductor coils).

[0040] Differential IDC core 621 provides differential inductance readout for input to a digital Schmitt trigger 651 (LS+ and LR-). As illustrated, the proximity switching response of the digital Schmitt trigger 651 is based on a difference (LS - LR) of LS and LR coil inductances provided as differential inductance readout from IDC core 621.

[0041] Alternatively, the digital Schmitt trigger 651 can be configured to switch based on a differential inductance readout that is a ratio of the LS and LR coil inductances. In addition, if differential inductance readout is a ratio of inductances LS/LR, such that, if LR is known, LS can be calculated, then the differential inductance ratio LS/LR, can be used directly for applications like weight scales, and for such implementations, the digital Schmitt trigger 651 is not required.

[0042] In summary, example embodiments of an inductive sensing system (such as for inductive proximity sensing/switching) include differential sense (Lsense) and reference (Lref) resonators with LS/LR sense/reference inductor coils, and a common capacitor Cc coupled to the LS and LR inductor coils. An inductance-to-data converter (IDC) is coupled to the Lsense/Lref resonators, through LSENSE/LREF output ports, coupled respectively to the LS/LR inductor coils, and through an LCOM input port to the common capacitor Cc. An Lsense driver, with an output coupled through the LSENSE output to the LS inductor coil, and with an input coupled to the LCOM input, is selectively enabled by an out enable signal OEsense. An Lref driver, with an output coupled through the LREF output to the LR inductor coil, and with an input coupled to the LCOM input, is selectively enabled by an out enable signal OEref. The OEsense and OEref signals are controlled to time-multiplex operation of the Lsense and Lref drivers.

[0043] The Lsense driver and Lsense resonator are operable as an Lsense ring oscillator to drive, when enabled by the OEsense signal, time-multiplexed Lsense resonator excitation signals through the LSENSE output to the Lsense resonator, to maintain Lsense resonator oscillation, based on resulting time-multiplexed Lsense resonance measurements acquired from the Lsense resonator through the LCOM input. The Lref driver and the Lref resonator are operable as an Lref ring oscillator to drive, when enabled by the OEref signal, time-multiplexed Lref resonator excitation signals through the LREF output to the Lref resonator, to maintain Lref resonator oscillation, based on resulting time-multiplexed Lref resonance measurements acquired from the Lref resonator through the LCOM input. Readout circuitry provides differential readout data based on the time-multiplexed Lsense and Lref resonance measurements, corresponding respectively to the inductances of the LS and LR inductor coils.

[0044] In other embodiments, the Lsense resonance measurements can correspond to a resonance state of the Lsense resonator, including a resonance state with steady-state oscillation, and the Lref resonance measurements can correspond to a resonance state of the Lref resonator, including a resonance state with steady-state oscillation. Differential readout data can be based on Lsense and Lref resonator oscillation frequency, as related respectively to the inductances of the LS/LR inductor coils. The LC-ring oscillators can be implemented with a Schmitt trigger coupled to the LCOM input to convert time-multiplexed Lsense/Lref resonance measurements from the Lsense/Lref resonators, to digital Schmitt trigger output based on predetermined high and low thresholds, with the Lsense/Lref drivers coupled to receive the Schmitt trigger output. The Lsense/Lref drivers can be fabricated with matched circuitry to provide matched output impedance, and layout matching can be used for the Lsense/Lref drivers to match respective parasitic capacitances at the outputs of the Lsense/Lref drivers. Further, parasitic capacitances at the Lsense/Lref driver outputs can be suppressed by either: (a) Ssense/Sref shorting switches connected across respectively the LS/LR inductor coils, and operable to selectively short the inactive inductor coil; or (b) Ssense/Sref shorting switches connected in series with respective bootstrap buffer amplifiers, across respectively the LS/LR inductor coils, the Ssense/Sref switches operable to selectively bootstrap a voltage from the common capacitor Cc across the inactive inductor coil.

[0045] Modifications are possible in the described embodiments, and other embodiments are possible, within the scope of the claims.

Claims

1. An inductance-to-data converter, i.e. IDC, integrated circuit suitable for operation with external sense and reference resonators Lsense and Lref, the Lsense and Lref resonators including respectively a sense inductor coil LS, and a reference inductor coil LR, and including a common resonator capacitor Cc, the IDC circuit comprising:

an LSENSE output for coupling to the LS inductor coil;
an LREF output for coupling to the LR inductor coil;
an LCOM input for coupling to the resonator capacitor Cc;
an Lsense driver with an output coupled to the LSENSE output, and an input coupled to the LCOM input, the Lsense driver selectively enabled by an out enable signal OEsense;
an Lref driver with an output coupled to the LREF output, and an input coupled to the LCOM input, the Lref driver selectively enabled by an out enable signal OEref;
the OEsense and OEref signals controlled to time-multiplex operation of the Lsense and Lref drivers;
the Lsense driver operable with the Lsense resonator as an Lsense ring oscillator to drive, when enabled by the OEsense signal, time-multiplexed Lsense resonator excitation signals through the LSENSE output, based on time-multiplexed Lsense resonance measurements received from the LCOM input;
the Lref driver operable with the Lref resonator as an Lref ring oscillator to drive, when enabled by the OEref signal, time-multiplexed Lref resonator excitation signals through the LREF output, based on time-multiplexed Lref resonance measurements received from the LCOM input; and
readout circuitry to provide differential readout data based on the time-multiplexed Lsense and Lref resonance measurements, corresponding respectively to inductances of the LS and LR inductor coils.

2. The integrated circuit of claim 1, wherein:

the LSENSE output is coupled to the external LS inductor coil;

the LREF output is coupled to the external LR inductor coil;
the LCOM input is coupled to the common resonator capacitor;
the time-multiplexed Lsense resonator excitation signals are driven through the LSENSE output to the Lsense resonator, to maintain Lsense resonator oscillation; and
the time-multiplexed Lref resonator excitation signals are driven through the LREF output to the Lref resonator, to maintain Lref resonator oscillation.

3. The integrated circuit of claim 1, further comprising: a Schmitt trigger coupled to the LCOM input to convert the time-multiplexed Lsense and Lref resonance measurements from the Lsense and Lref resonators, to a digital Schmitt trigger output, based on predetermined high and low thresholds, provided to the Lsense and Lref drivers.

4. An inductive sensing system, comprising:

differential sense Lsense and reference Lref resonators, including: a sense inductor coil LS; a reference inductor coil LR; and a common capacitor Cc coupled to the LS and LR inductor coils;
the IDC according to claim 1 coupled to the Lsense and Lref resonators, through LSENSE and LREF outputs coupled respectively to the LS and LR inductor coils, and through an LCOM input coupled to the common capacitor Cc.

5. The integrated circuit of claim 2 or the system of claim 4, wherein:

the Lsense resonance measurements correspond to a resonance state of the Lsense resonator, including a resonance state with steady-state oscillation; and
the Lref resonance measurements correspond to a resonance state of the Lref resonator, including a resonance state with steady-state oscillation.

6. The integrated circuit of claim 1 or the system of claim 4, wherein the readout circuitry provides differential readout data based on Lsense and Lref resonator oscillation frequency, as related respectively to the inductances of the L_S and L_R inductor coils.

7. The system of claim 4, wherein the LC-ring oscillators are implemented with a Schmitt trigger coupled to the LCOM input to convert the time-multiplexed Lsense and Lref resonance measurements from the Lsense and Lref resonators, to a digital Schmitt trigger output, based on predetermined high and low thresholds, provided to the Lsense and Lref drivers.

8. The integrated circuit of claim 1 or the system of claim 4, wherein:

the Lsense and Lref drivers are fabricated with matched circuitry to provide matched output impedance; and
layout matching is used for the Lsense and Lref drivers to match respective parasitic capacitances at the outputs of the Lsense and Lref drivers.

9. The integrated circuit of claim 2 or the system of claim 4, further comprising one of:

Ssense and Sref shorting switches connected across respectively the LS and LR inductor coils, and operable to selectively short an inactive one of the inductor coils; and
Ssense and Sref shorting switches connected in series with respective bootstrap buffer amplifiers, across respectively the LS and LR inductor coils, the Ssense and Sref switches operable to selectively bootstrap a voltage from the common capacitor Cc across an inactive one of the inductor coils.

10. The integrated circuit of claim 2 or the system of claim 4, for use as an inductive switch, wherein:

the LS inductor coil is disposed to detect proximity of a conductive target; and
the readout circuitry provides differential readout data corresponding to a proximity event in which the target is at a pre-defined proximity to the L_S inductor coil.

11. A method for inductive sensing suitable for use with sense and reference resonators Lsense and Lref, the Lsense and Lref resonators including respectively a sense inductor coil L_S, and a reference inductor coil L_R, and including a common resonator capacitor Cc, comprising:

driving the Lsense resonator as a time-multiplexed Lsense ring oscillator, including driving time-multiplexed Lsense resonator excitation signals into the Lsense resonator, to maintain Lsense resonator oscillation, based on resulting time-multiplexed Lsense resonance measurements input to the Lsense ring oscillator from the Lsense resonator;
driving the Lref resonator as a time-multiplexed Lref ring oscillator, including driving time-multiplexed Lref resonator excitation signals into the Lref resonator, to maintain Lsense resonator oscillation, based on resulting time-multiplexed Lref resonance measurements input to the Lref

ring oscillator from the Lref resonator;
time-multiplexing the operation of the Lsense and Lref ring oscillators to enable sharing the common resonator capacitor Cc by the Lsense and Lref resonators; and
providing differential readout data based on the time-multiplexed Lsense and Lref resonance measurements, corresponding respectively to inductances of the LS and LR inductor coils.

12. The method of claim 11, wherein:

the Lsense resonance measurements correspond to a resonance state of the Lsense resonator, including a resonance state with steady-state oscillation; and
the Lref resonance measurements correspond to a resonance state of the Lref resonator, including a resonance state with steady-state oscillation.

13. The method of claim 11, wherein the differential readout data is based on Lsense and Lref resonator oscillation frequency, as related respectively to the inductances of the LS and LR inductor coils.

14. The method of claim 11, where the LC-ring oscillators are implemented with a Schmitt trigger coupled to the LCOM input to convert the time-multiplexed Lsense and Lref resonance measurements from the Lsense and Lref resonators, to a digital Schmitt trigger output, based on predetermined high and low thresholds, provided to the Lsense and Lref drivers..

15. The method of claim 11, further comprising one of:

selectively shorting an inactive one of the inductor coils; and
selectively bootstrapping a voltage from the common resonator capacitor Cc across an inactive one of the inductor coils.

16. The method of claim 11, for use in inductive switching, wherein:

the LS inductor coil is disposed to detect proximity of a conductive target; and
the differential readout data corresponding to a proximity event in which the target is at a predefined proximity to the LS inductor coil.

Patentansprüche

1. Integrierte Induktivität-zu-Daten-Umsetzer-Schaltung, d. h. integrierte IDC-Schaltung, die für einen Betrieb mit einem externen Erfassungs- und einem externen Referenzresonator, Lsense bzw. Lref, geeignet ist, wobei der Lsense- und der Lref-Resonator jeweils eine Erfassungsinduktionsspule, LS, und eine Referenzinduktionsspule, LR, enthalten, und einen gemeinsamen Resonatorkondensator, Cc, enthalten, wobei die IDC-Schaltung Folgendes umfasst:

einen LSENSE-Ausgang zum Koppeln an die LS-Induktionsspule;
einen LREF-Ausgang zum Koppeln an die LR-Induktionsspule;
einen LCOM-Eingang zum Koppeln an den Resonatorkondensator, Cc;
eine Lsense-Ansteuerung mit einem Ausgang, der an den LSENSE-Ausgang gekoppelt ist, und einem Eingang, der an den LCOM-Eingang gekoppelt ist, wobei die Lsense-Ansteuerung wahlweise durch ein Aus-Aktivierungssignal, OEsense, aktiviert wird;
eine Lref-Ansteuerung mit einem Ausgang, der an den LREF-Ausgang gekoppelt ist, und einem Eingang, der an den LCOM-Eingang gekoppelt ist, wobei die Lref-Ansteuerung wahlweise durch ein Aus-Aktivierungssignal, OEref, aktiviert wird;
wobei das OEsense- und das OEref-Signal durch einen Zeitmultiplex-Betrieb der Lsense- und der Lref-Ansteuerung gesteuert werden;
wobei die Lsense-Ansteuerung mit dem Lsense-Resonator als einem Lsense-Ringoszillator dann, wenn sie durch das OEsense-Signal aktiviert wird, betreibbar ist, zeitmultiplexierte Lsense-Resonatoranregungssignale durch den LSENSE-Ausgang anhand von zeitmultiplexierten Lsense-Resonatormessungen, die von dem LCOM-Eingang empfangen werden, zu lenken;
wobei die Lref-Ansteuerung mit dem Lref-Resonator als einem Lref-Ringoszillator dann, wenn sie durch das OEref-Signal aktiviert wird, betreibbar ist, zeitmultiplexierte Lres-Resonator-Anregungssignale durch den LREF-Ausgang anhand von zeitmultiplexierten Lref-Resonanzmessungen, die von dem LCOM-Eingang empfangen werden, zu lenken; und
eine Ausleseschaltung, um differenzielle Auslesedaten anhand der zeitmultiplexierten Lsense- und Lref-Resonanzmessungen zu liefern, die jeweils Induktivitäten der LS- und der LR-Induktionsspule entsprechen.

2. Integrierte Schaltung nach Anspruch 1, wobei:

der LSENSE-Ausgang an die externe LS-Induktionsspule gekoppelt ist;
der LREF-Ausgang an die externe LR-Induktionsspule gekoppelt ist;
der LCOM-Eingang an den gemeinsamen Resonatorkondensator gekoppelt ist;

die zeitmultiplexierten Lsense-Resonatoranregungssignale durch den LENSE-Ausgang zu dem Lsense-Resonator gelenkt werden, um eine Lsense-Resonatorschwingung aufrechtzuerhalten; und

die zeitmultiplexierten Lref-Resonatoranregungssignale durch den LREF-Ausgang zu dem Lref-Resonator gelenkt werden, um die Lref-Resonatorschwingung aufrechtzuerhalten.

3. Integrierte Schaltung nach Anspruch 1, die ferner Folgendes umfasst:
einen Schmitt-Trigger, der an den LCOM-Eingang gekoppelt ist, um die zeitmultiplexierten Lsense- und Lref-Resonanzmessungen von dem Lsense- und dem Lref-Resonator anhand eines vorbestimmte hohen und niedrigen Schwellenwerts, die an die Lsense- und die Lref-Ansteuerung geliefert werden, in einen digitalen Schmitt-Trigger-Ausgang umzusetzen.

4. Induktives Erfassungssystem, das Folgendes umfasst:

einen differenziellen Erfassungs- und einen differenziellen Referenzresonator, Lsense bzw. Lref, die Folgendes enthalten: eine Erfassungsinduktionsspule, LS; eine Referenzinduktionsspule, LR; und einen gemeinsamen Kondensator, Cc, der an die LS- und die LR-Induktionsspule gekoppelt ist,

wobei die IDC nach Anspruch 1 durch einen LSENSE- und einen LREF-Ausgang, die jeweils an die LS- und die LR-Induktionsspule gekoppelt sind, und durch einen LCOM-Eingang, der an den gemeinsamen Kondensator, Cc, gekoppelt ist, an den Lsense- und den Lref-Resonator gekoppelt ist.

5. Integrierte Schaltung nach Anspruch 2 oder System nach Anspruch 4, wobei:

die Lsense-Resonanzmessungen einem Resonanzzustand des Lsense-Resonators entsprechen, einschließlich eines Resonanzzustands mit einer Schwingung eines stabilen Zustands; und

die Lref-Resonanzmessungen einem Resonanzzustand des Lref-Resonators entsprechen, einschließlich eines Resonanzzustands mit einer Schwingung eines stabilen Zustands.

6. Integrierte Schaltung nach Anspruch 1 oder das System nach Anspruch 4, wobei die Ausleseschaltung differenzielle Auslesedaten anhand der Lsense- und der Lref-Resonatorschwingungsfrequenz liefert, wie jeweils auf die Induktivitäten der LS- und LR-Induktionsspule bezogen.

7. System nach Anspruch 4, wobei die LC-Ring- Oszillatoren mit einem Schmitt-Trigger implementiert sind, der an den LCOM-Eingang gekoppelt ist, um die zeitmultiplexierten Lsense- und Lref-Resonanzmessungen von dem Lsense- und dem Lref-Resonator anhand eines vorbestimmten hohen und niedrigen Schwellenwerts, die an die Lsense- und die Lref-Ansteuerung geliefert werden, zu einem digitalen Schmitt-Triggerausgang umzusetzen.

8. Integrierte Schaltung nach Anspruch 1 oder System nach Anspruch 4, wobei:

die Lsense- und die Lref-Ansteuerung mit angepasster Schaltung hergestellt werden, um eine angepasste Ausgangsimpedanz zu liefern; und
eine Layoutanpassung für die Lsense- und die Lref-Ansteuerung verwendet wird, um jeweilige parasitäre Kapazitäten an den Ausgängen der Lsense- und der Lref-Ansteuerung anzupassen.

9. Integrierte Schaltung nach Anspruch 2 oder System nach Anspruch 4, das ferner eines des Folgenden umfasst:

einen Ssense- und einen Sref-Kurschlussschalter, die jeweils über die LS- und die LR-Induktionsspule angeschlossen sind und betreibbar sind, wahlweise eine inaktive der Induktionsspulen kurzzuschließen; und
einen Ssense- und einen Sref-Kurzschlussschalter, die in Reihe mit jeweiligen Bootstrap-Pufferverstärkern jeweils über die LS- und die LR-Induktionsspule angeschlossen sind, wobei der Ssense- und der Sref-Schalter betreibbar sind, wahlweise eine Spannung von dem gemeinsamen Kondensator, Cc, über eine inaktive der Induktionsspulen urzuladen.

10. Integrierte Schaltung nach Anspruch 2 oder System nach Anspruch 4 für die Verwendung als ein induktiver Schalter, wobei:

die LS-Induktionsspule angeordnet ist, um die Nähe eines leitenden Ziels zu detektieren; und
die Ausleseschaltung differenzielle Auslesedaten liefert, die einem Näheereignis entsprechen, in dem sich das Ziel in einer vordefinierten Nähe zu der LS-Induktionsspule befindet.

11. Verfahren zum induktiven Erfassen, das für die Verwendung mit einem Erfassungs- und einem Referenzresonator, Lsense und Lref, geeignet ist, wobei der Lsense- und der Lref-Resonator jeweils eine Erfassungsinduktionsspule, L_S, und eine Referenzinduktionsspule L_R, enthalten, und einen gemeinsamen Resonanzkondensator, Cc, enthalten, das Folgendes umfasst:

Ansteuern des Lsense-Resonators als einen zeitmultiplexierten Lsense-Ringoszillator, das enthält, zeitmultiplexierte Lsense-Resonatoranregungssignale in den Lsense-Resonator zu lenken, um eine Lsense-Resonator-Schwingung aufrechtzuerhalten, anhand sich ergebender zeitmultiplexierter Lsense-Resonanzmessungen, die in den Lsense-Ringoszillator von dem Lsense-Resonator eingegeben werden;
Ansteuern des Lref-Resonators als einen zeitmultiplexierten Lref-Ringoszillator, das enthält, zeitmultiplexierte Lref-Resonatoranregungssignale in den Lref-Resonator zu lenken, um eine Lsense-Resonatorsschwingung aufrechtzuerhalten, anhand sich ergebender zeitmultiplexierter Lref-Resonatormessungen, die in den Lref-Ringoszillator von dem Lref-Resonator eingegeben werden;
Zeitpultiplexen des Betriebs des Lsense- und des Lref-Ringoszillators, um zu ermöglichen, den gemeinsamen Resonatorkondensator, Cc, durch den Lsense- und den Lref-resonator gemeinsam zu nutzen; und
Liefern differenzieller Auslesedaten anhand der zeitmultiplexierten Lsense- und Lref-Resonanzmessungen, die jeweils Induktivitäten der Ls- und der LR-Induktionsspule entsprechen.

12. Verfahren nach Anspruch 11, wobei:

die Lsense-Resonanzmessungen einem Resonanzzustand des Lsense-Resonators entsprechen, einschließlich eines Resonanzzustands mit Schwingung eines stabilen Zustands; und
die Lref-Resonanzmessungen einem Resonanzzustand des Lref-Resonators entsprechen, einschließlich eines Resonanzzustands mit Schwingung eines stabilen Zustands.

13. Verfahren nach Anspruch 11, wobei die differenziellen Auslesedaten auf einer Lsense- und einer Lref-Resonatorschwingungsfrequenz beruhen, wie jeweils auf die Induktivitäten der LS- und der LR-Induktionsspule bezogen.

14. Verfahren nach Anspruch 11, wobei die LC-Ringoszillatoren mit einem Schmitt-Trigger implementiert sind, der an den LCOM-Eingang gekoppelt ist, um die zeitmultiplexierten Lsense- und Lref-Resonanzmessungen von dem Lsense- und dem Lref-Resonator in einen digitalen Schmitt-Trigger-Ausgang umzusetzen, anhand eines vorbestimmten hohen und niedrigen Schwellenwerts, die an die Lsense- und die Lref-Ansteuerung geliefert werden.

15. Verfahren nach Anspruch 11, das ferner eines der Folgenden umfasst:

wahlweise Kurzschließen einer inaktiven der Induktionsspulen; und
wahlweise Urladen einer Spannung von dem gemeinsamen Resonatorkondensator, Cc, über eine inaktive der Induktionsspulen.

16. Verfahren nach Anspruch 11 für die Verwendung in einer induktiven Schaltung, wobei:

die LS-Induktionsspule angeordnet ist, um die Nähe eines leitenden Ziels zu detektieren; und
die differenziellen Auslesedaten einem Näheereignis entsprechen, in dem sich das Ziel in einer vordefinierten Nähe zu der LS-Induktionsspule befindet.

Revendications

1. Circuit intégré de convertisseur d'inductance en données, à savoir IDC, approprié pour fonctionner avec des résonateurs de détection externe et de référence, Lsense et Lref, les résonateurs Lsense et Lref comprenant respectivement une bobine d'inducteur de détection LS et une bobine d'inducteur de référence LR, et comprenant un condensateur de résonateur commun Cc, le circuit IDC comprenant :

une sortie LSENSE pour le couplage à la bobine d'inducteur LS ;
une sortie LREF pour le couplage à la bobine d'inducteur LR ; une entrée LCOM pour le couplage au condensateur de résonateur Cc ;
un circuit d'attaque Lsense avec une sortie couplée à la sortie LSENSE, et une entrée couplée à l'entrée LCOM, le circuit d'attaque Lsense étant activé sélectivement par un signal d'activation de sortie OEsense ;
un circuit d'attaque Lref avec une sortie couplée à la sortie LREF, et une entrée couplée à l'entrée LCOM, le circuit d'attaque Lref étant activé sélectivement par un signal d'activation de sortie OEref ;
les signaux OEsense et OEref étant commandés pour multiplexer dans le temps le fonctionnement des circuits d'attaque Lsense et Lref ;
le circuit d'attaque Lsense fonctionnant avec le résonateur Lsense en tant qu'oscillateur en anneau Lsense pour commander, lorsqu'il est activé par le signal OEsense, des signaux d'excitation de résonateur Lsense multiplexés dans le temps à travers la sortie LSENSE, sur la base des mesures de résonance Lsense multiplexées dans le temps reçues de l'entrée LCOM ;
le circuit d'attaque Lref fonctionnant avec le résonateur Lref en tant qu'oscillateur en anneau Lref pour commander, lorsqu'il est activé par le signal OEref, des signaux d'excitation de réso-

nateur Lref multiplexés dans le temps à travers la sortie LREF, sur la base des mesures de résonance Lref multiplexées dans le temps reçues de l'entrée LCOM ; et
un circuit de lecture pour fournir des données de lecture différentielles basées sur les mesures de résonance Lsense et Lref multipliées dans le temps, correspondant respectivement aux inductances des bobines d'inducteur LS et LR.

2. Circuit intégré selon la revendication 1, dans lequel :

la sortie LSENSE est couplée à la bobine d'inducteur LS externe ;
la sortie LREF est couplée à la bobine d'inducteur LR externe ;
l'entrée LCOM est couplée au condensateur de résonateur commun ;
les signaux d'excitation de résonateur Lsense multiplexés dans le temps sont commandés par la sortie LSENSE vers le résonateur Lsense, pour maintenir l'oscillation du résonateur Lsense ; et
les signaux d'excitation de résonateur Lref multiplexés dans le temps sont commandés par la sortie LREF vers le résonateur Lref, pour maintenir l'oscillation du résonateur Lref.

3. Circuit intégré selon la revendication 1, comprenant en outre :
un déclencheur Schmitt couplé à l'entrée LCOM pour convertir les mesures de résonance Lsense et Lref multipliées dans le temps des résonateurs Lsense et Lref en une sortie de déclencheur Schmitt numérique, sur la base de seuils haut et bas prédéterminés, fournis aux circuits d'attaque Lsense et Lref.

4. Système de détection inductif, comprenant :

des résonateurs de détection différentielle et de référence Lsense et Lref, comprenant : une bobine d'inducteur de détection LS ; une bobine d'inducteur de référence LR ; et un condensateur commun Cc couplé aux bobines d'inducteur LS et LR ;
l'IDC selon la revendication 1 couplé aux résonateurs Lsense et Lref, par les sorties LSENSE et LREF couplées respectivement aux bobines d'inducteur LS et LR, et par une entrée LCOM couplée au condensateur commun Cc.

5. Circuit intégré selon la revendication 2 ou système selon la revendication 4, **caractérisé en ce que** :

les mesures de résonance Lsense correspondent à un état de résonance du résonateur Lsense, dont un état de résonance avec oscillation en régime permanent ; et
les mesures de résonance Lref correspondent à un état de résonance du résonateur Lref, dont un état de résonance avec oscillation en régime permanent.

6. Circuit intégré selon la revendication 1 ou système selon la revendication 4, dans lequel le circuit de lecture fournit des données de lecture différentielles basées sur les fréquences d'oscillation des résonateurs Lsense et Lref, respectivement liées aux inductances des bobines d'inducteur L_S et L_R.

7. Système selon la revendication 4, dans lequel les oscillateurs en anneau LC sont mis en œuvre avec un déclencheur Schmitt couplé à l'entrée LCOM pour convertir les mesures de résonance Lsense et Lref multipliées dans le temps des résonateurs Lsense et Lref, en une sortie de déclencheur numérique Schmitt, sur la base de seuils haut et bas prédéterminés, fournis aux circuits d'attaque Lsense et Lref.

8. Circuit intégré selon la revendication 1 ou système selon la revendication 4, dans lequel :

les circuits d'attaque Lsense et Lref sont fabriqués avec un circuit adapté pour fournir une impédance de sortie adaptée ; et
une adaptation de la disposition est utilisée pour les circuits d'attaque Lsense et Lref afin de faire correspondre les capacités parasites respectives aux sorties des circuits d'attaque Lsense et Lref.

9. Circuit intégré selon la revendication 2 ou système selon la revendication 4, comprenant en outre l'un des commutateurs suivants :

des commutateurs de court-circuit Ssense et Sref connectés respectivement aux bobines d'inducteur LS et LR, et utilisables pour court-circuiter de manière sélective une bobine inactive des bobines d'inducteur ; et
des commutateurs de court-circuit Ssense et Sref sont connectés en série avec des amplificateurs tampons auto-élévateurs cathodiques respectifs, respectivement sur les bobines d'inductance LS et LR, les commutateurs Ssense et Sref étant utilisables pour amorcer sélectivement une tension du condensateur commun Cc sur une bobine inactive des bobines d'inducteur.

10. Circuit intégré selon la revendication 2 ou système selon la revendication 4, destiné à être utilisé comme commutateur inductif, dans lequel :

la bobine d'inducteur LS est disposée de manière à détecter la proximité d'une cible conductrice ; et le circuit de lecture fournit des données de lecture différentielle correspondant à un événement de proximité où la cible est à une proximité prédéfinie de la bobine d'inducteur Ls.

11. Procédé de détection inductive approprié pour une utilisation avec des résonateurs de détection et de référence Lsense et Lref, les résonateurs Lsense et Lref comprenant respectivement une bobine d'inducteur de détection L_S et une bobine d'inducteur de référence L_R, et comprenant un condensateur de résonateur commun Cc, comprenant :

de commander le résonateur Lsense en tant qu'oscillateur en anneau Lsense multiplexé dans le temps, y compris de commander des signaux d'excitation de résonateur Lsense multiplexés dans le temps dans le résonateur Lsense, pour maintenir l'oscillation de résonateur Lsense, sur la base des mesures de résonance Lsense multiplexées dans le temps résultantes entrées dans l'oscillateur en anneau Lsense depuis le résonateur Lsense ;
de commander le résonateur Lref en tant qu'oscillateur en anneau Lref multiplexé dans le temps, y compris de commander des signaux d'excitation de résonateur Lref multiplexés dans le temps dans le résonateur Lref, pour maintenir l'oscillation de résonateur Lsense, sur la base des mesures de résonance Lref multiplexées dans le temps entrées dans l'oscillateur en anneau Lref depuis le résonateur Lref ;
de multiplexer dans le temps le fonctionnement des oscillateurs en anneau Lsense et Lref pour permettre le partage du condensateur de résonateur commun Cc par les résonateurs Lsense et Lref ; et
de fournir des données de lecture différentielle basées sur les mesures de résonance Lsense et Lref multiplexées dans le temps, correspondant respectivement aux inductances des bobines d'inducteur LS et LR.

12. Procédé selon la revendication 11, dans lequel :

les mesures de résonance Lsense correspondent à un état de résonance du résonateur Lsense, dont un état de résonance avec oscillation en régime permanent ; et
les mesures de résonance Lref correspondent à un état de résonance du résonateur Lref, dont un état de résonance avec oscillation en régime permanent.

13. Procédé selon la revendication 11, dans lequel les données de lecture différentielle sont basées sur la fréquence d'oscillation de résonateur Lsense et Lref, respectivement liées aux inductances des bobines d'inducteur LS et LR.

14. Procédé selon la revendication 11, dans lequel les oscillateurs en anneau LC sont mis en œuvre avec un déclencheur Schmitt couplé à l'entrée LCOM pour convertir les mesures de résonance Lsense et Lref multiplexées dans le temps des résonateurs Lsense et Lref, en une sortie de déclencheur numérique Schmitt, sur la base de seuils haut et bas prédéterminés, fournis aux circuits d'attaque Lsense et Lref.

15. Procédé selon la revendication 11, comprenant en outre l'une des étapes suivantes :

court-circuiter sélectivement une bobine inactive des bobines d'inducteur ; et
amorcer sélectivement une tension du condensateur de résonateur commun Cc à travers une bobine inactive des bobines d'inducteur.

16. Procédé selon la revendication 11, destiné à être utilisé pour une commutation inductive, dans lequel :

la bobine d'inducteur LS est disposée de manière à détecter la proximité d'une cible conductrice ; et
les données de lecture différentielle correspondent à un événement de proximité où la cible est à une proximité prédéfinie de la bobine d'inducteur LS.

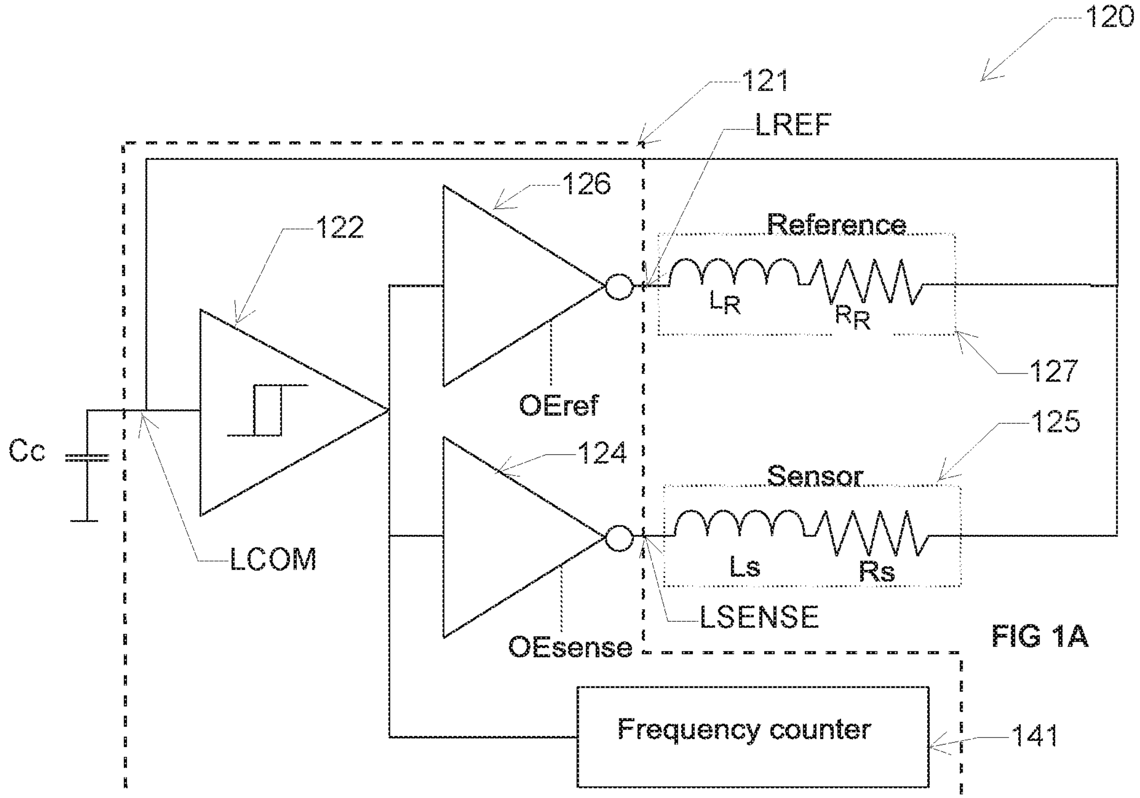

120
121
LREF
126
122
Reference
L_R
R_R
127
OEref
125
Cc
124
Sensor
LCOM
Ls
Rs
LSENSE
OEsense
Frequency counter
141

FIG 1A

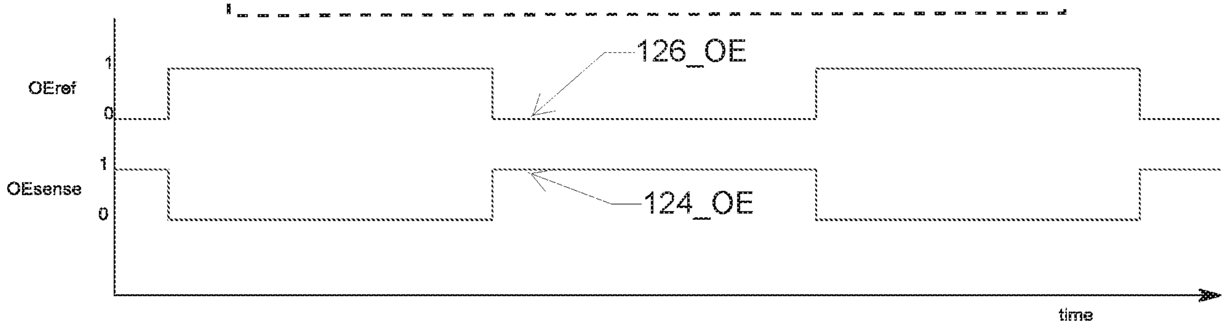
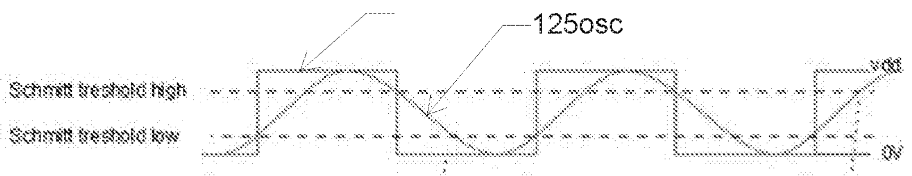

OEref
1
0
126_OE
OEsense
1
0
124_OE
time

FIG 1B

FIG 2B



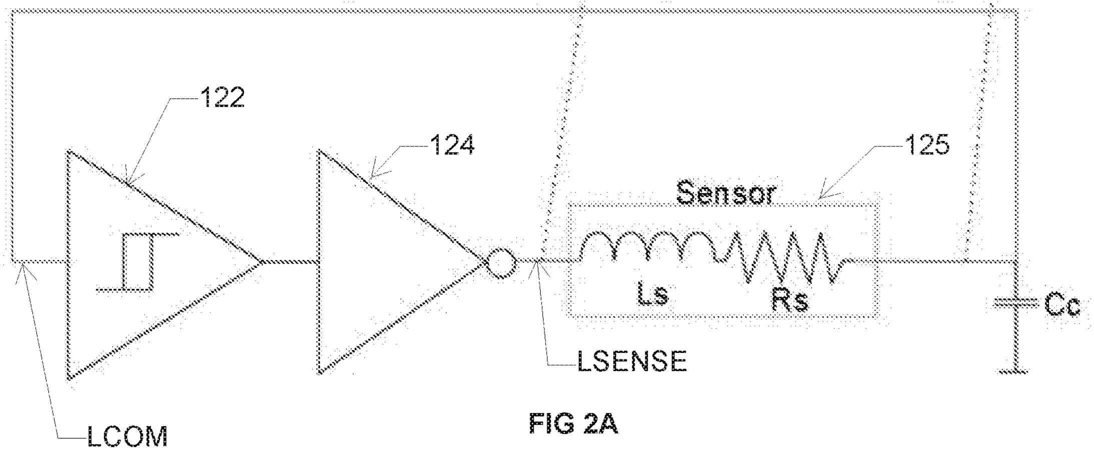


FIG 2A

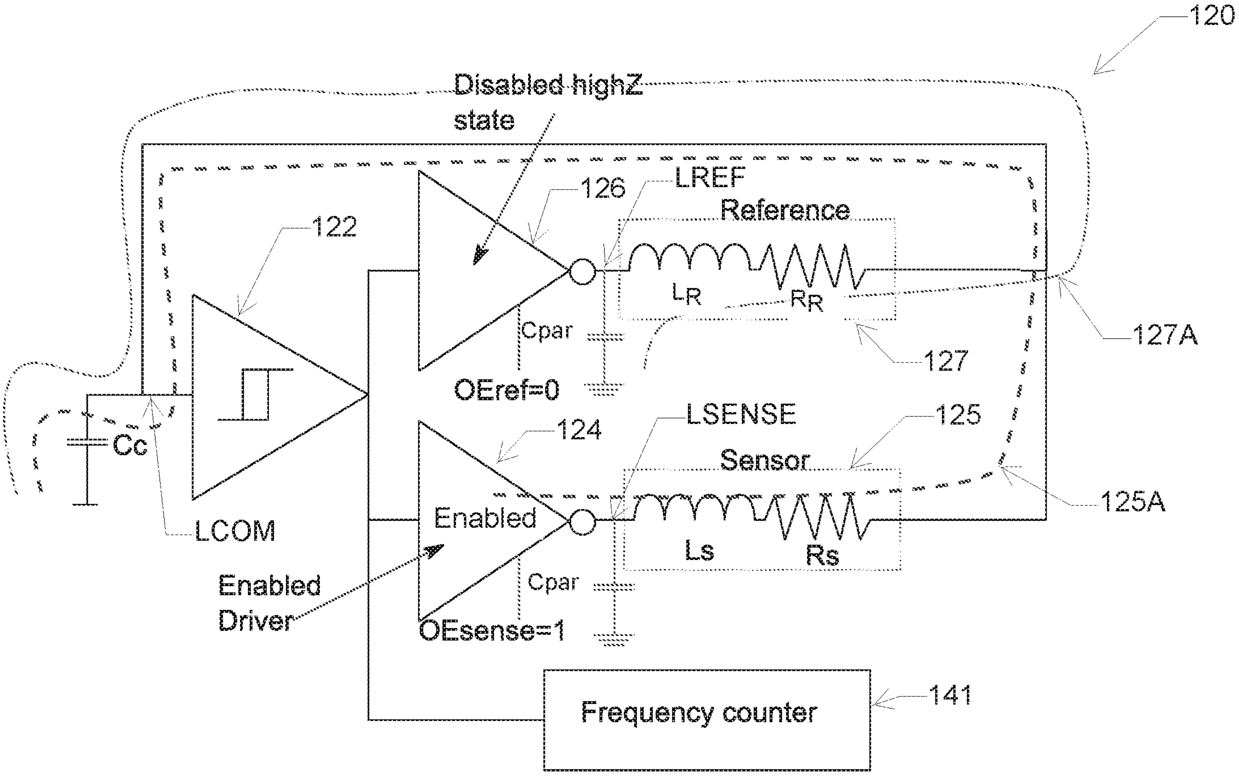


FIG 3

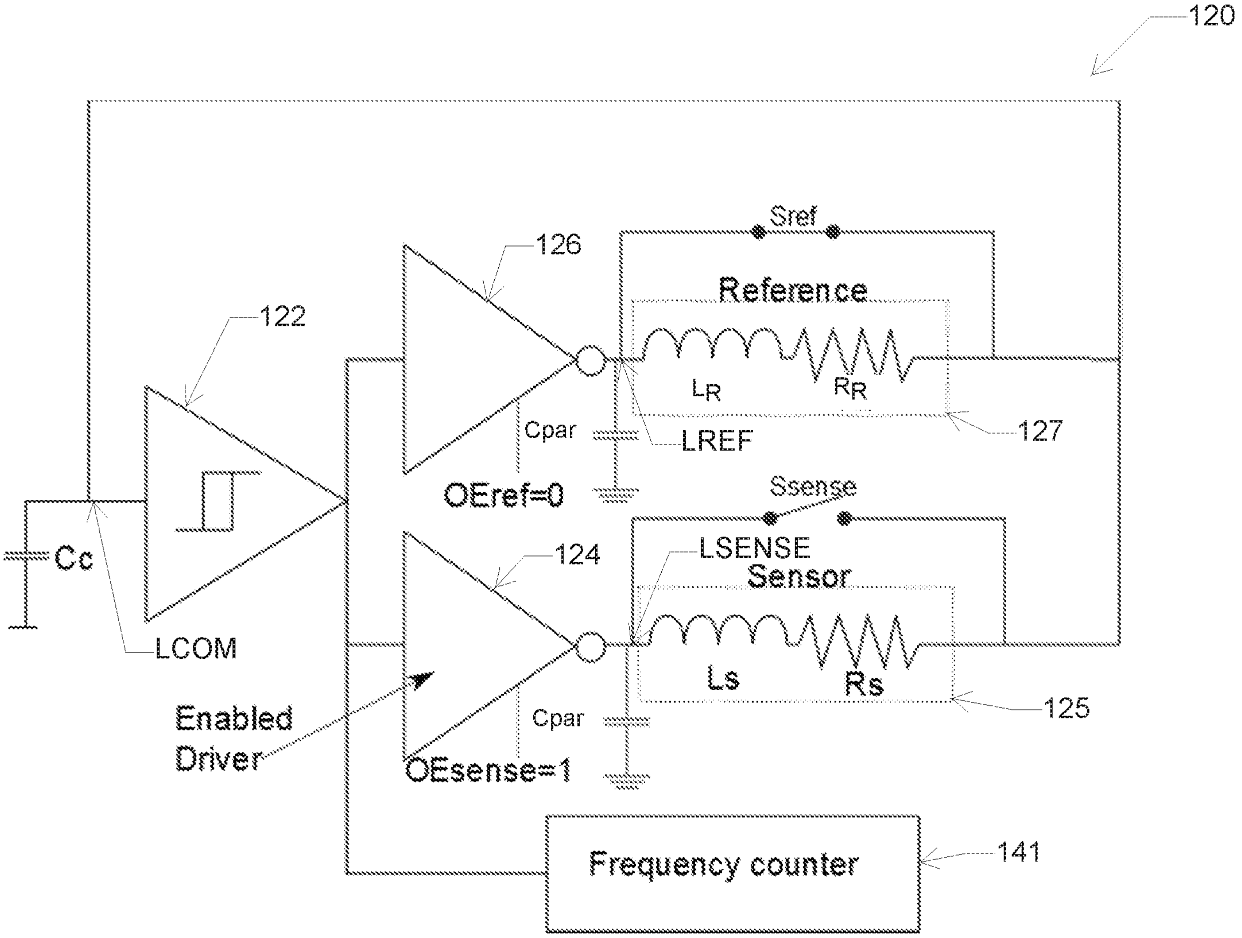

120
Sref
126
Reference
122
LR
RR
Cpar
LREF
127
OEref=0
Ssense
Cc
124
LSENSE
Sensor
LCOM
Ls
Rs
125
Enabled
Driver
Cpar
OEsense=1
Frequency counter
141

FIG 4

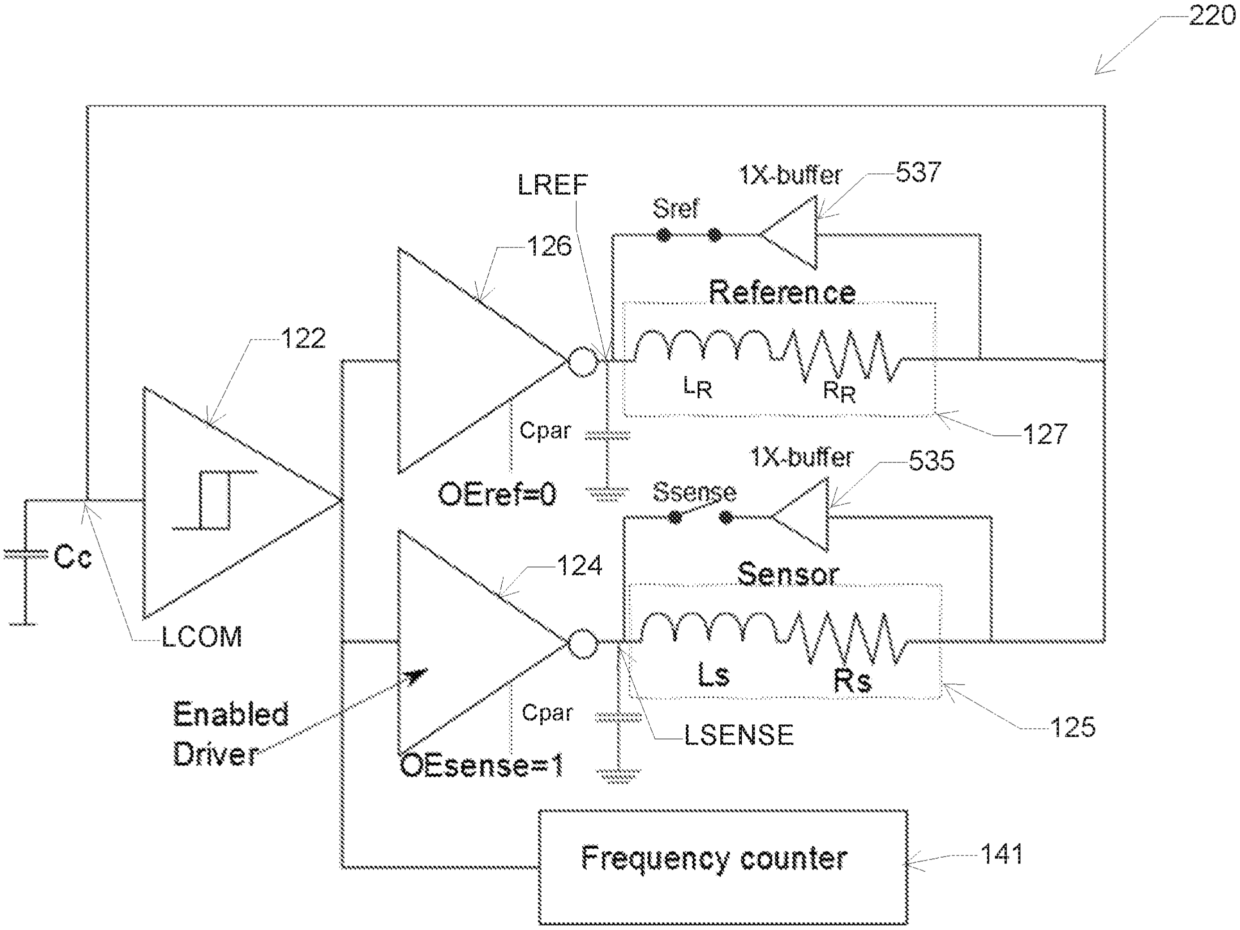

220
LREF
1X-buffer
537
Sref
126
Reference
122
LR
RR
Cpar
127
1X-buffer
535
OEref=0
Ssense
Cc
Sensor
124
LCOM
Ls
Rs
Enabled
Driver
Cpar
LSENSE
125
OEsense=1
Frequency counter
141

FIG 5

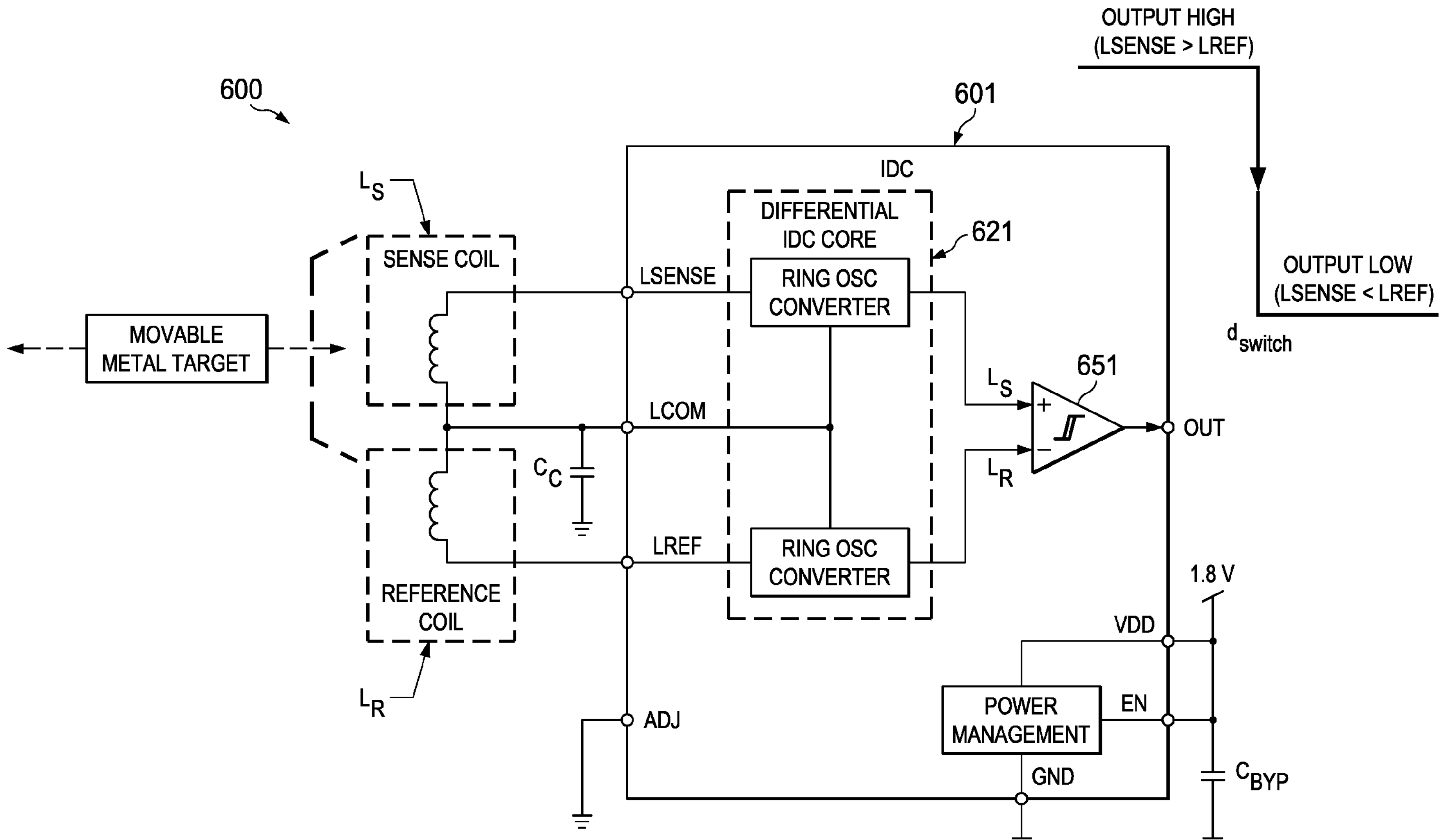

OUTPUT HIGH
(LSENSE > LREF)
600
601
IDC
DIFFERENTIAL
IDC CORE
621
L_S
SENSE COIL
LSENSE
RING OSC
CONVERTER
OUTPUT LOW
(LSENSE < LREF)
MOVABLE
METAL TARGET
d_{switch}
L_S
651
+
LCOM
OUT
−
C_C
L_R
LREF
RING OSC
CONVERTER
1.8 V
REFERENCE
COIL
VDD
L_R
ADJ
POWER
MANAGEMENT
EN
GND
C_{BYP}

FIG. 6A

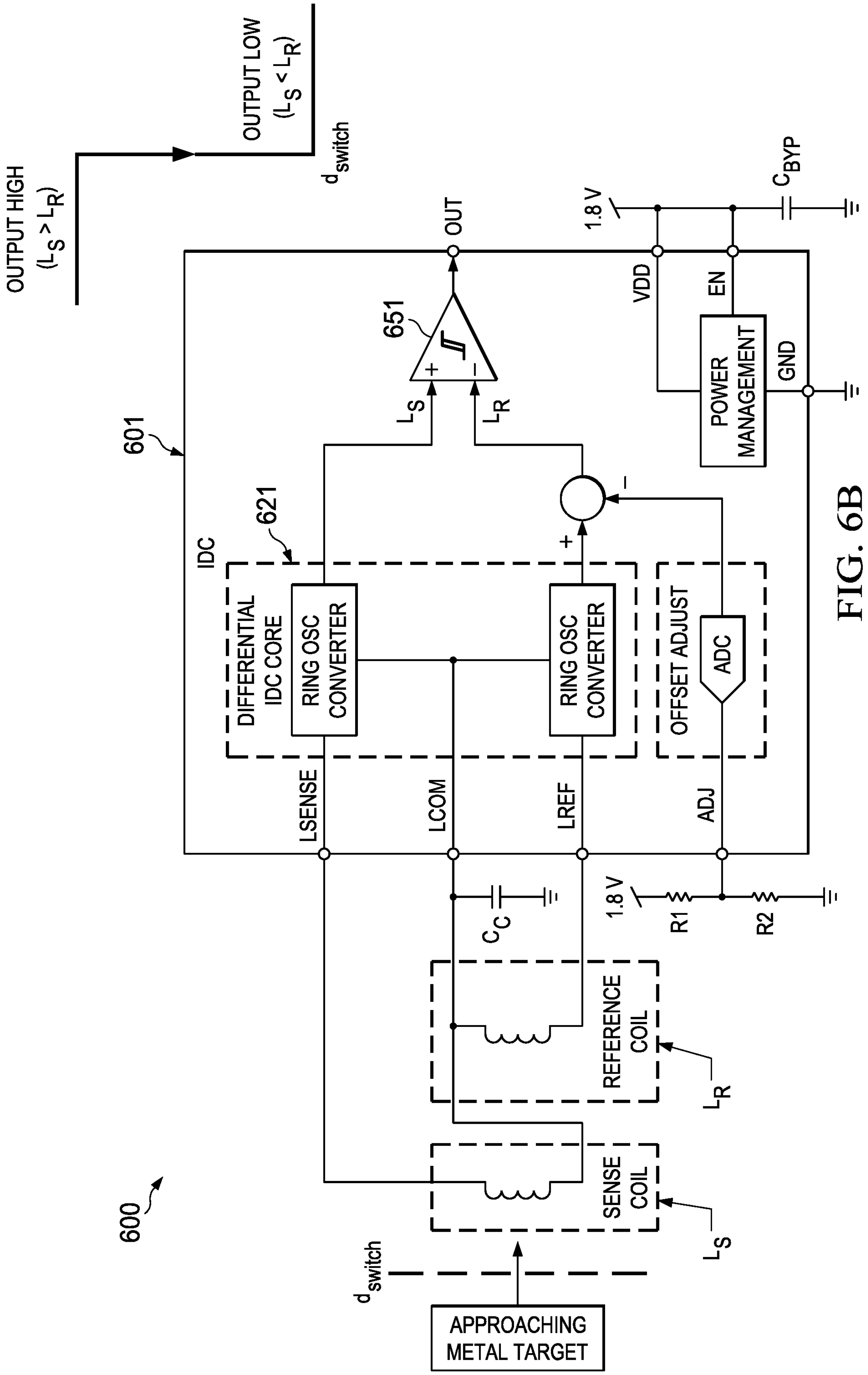

OUTPUT HIGH
($L_S > L_R$)
OUTPUT LOW
($L_S < L_R$)
d_{switch}
OUT
1.8 V
C_{BYP}
651
601
VDD
EN
L_S
L_R
POWER MANAGEMENT
GND
621
IDC
DIFFERENTIAL IDC CORE
RING OSC CONVERTER
RING OSC CONVERTER
OFFSET ADJUST
ADC
+
−
LSENSE
LCOM
LREF
ADJ
1.8 V
R1
R2
C_C
REFERENCE COIL
L_R
SENSE COIL
L_S
600
d_{switch}
APPROACHING METAL TARGET

FIG. 6B

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- EP 0371261 A **[0006]**