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(54) Method of Operating a Capacitive Sensing System with Heater as Guard Electrode.

(57) A capacitive sensing device (12; 54; 62; 78) comprises a sense-guard capacitive sensor (14). The at least one guard electrode (18; 84) is designed as an electric heating member. A periodic signal voltage source (24) is configured for providing a periodic electrical measurement signal to the at least one sense electrode (16) and to the at least one guard electrode (18; 84). A complex impedance measurement circuit (26) is electrically connected to the periodic signal voltage source (24) and to the at least one sense electrode (16), and is configured for measuring complex sense currents generated in the at least one sense electrode (16), and for determining a complex impedance based on the measured complex sense current. An AC decoupling circuit (34; 56; 64) is provided that has an input interface (36) that is electrically connectable to an electric heater power unit (50), and an output interface (38) that is electrically connected to ends of the at least one guard electrode (18; 84), for providing electric power to the at least one guard electrode (18; 84).

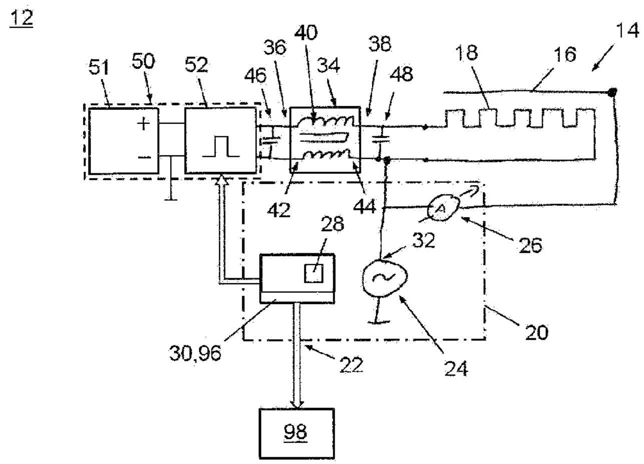

Fig. 2

Method of Operating a Capacitive Sensing System with Heater as Guard Electrode

Technical field

[0001] The invention relates to a capacitive sensing device with a sense-guard capacitive sensor, in particular for automotive applications, a method for determining a complex impedance of a guard-sense capacitive sensor operated using such capacitive sensing device, and a software module for automatically carrying out such method.

Background of the Invention

[0002] Capacitive sensors and capacitive measurement and/or detection devices employing capacitive sensors have a wide range of applications, and are among others used for the detection of the presence and/or the position of a conductive body or body portion in the vicinity of an antenna electrode. As used herein, the term “capacitive sensor” designates a sensor, which generates a signal responsive to the influence of what is being sensed (a person, a part of a person’s body, a pet, an object, etc.) upon an electric field. A capacitive sensor generally comprises at least one antenna electrode, to which is applied an oscillating electric signal and which thereupon emits an electric field into a region of space proximate to the antenna electrode, while the sensor is operating. The sensor comprises at least one sensing electrode – which may be identical with or different from emitting antenna electrodes – at which the influence of an object or living being on the electric field is detected.

[0003] In the field of automotive vehicle sensor application it is known to employ capacitive sensors for providing input to Automatic Driver Assistance Systems (ADAS), for instance for the purpose of a seat belt reminder (SBR) system or an activation control for an auxiliary restraint system (ARS). Sensed signals can serve as a basis for making decisions by an ADAS, for instance for a decision to deploy an air bag system to a specific vehicle seat or not.

[0004] Capacitive occupant sensing systems have been proposed in great variety, e.g. for controlling the deployment of one or more airbags, such as e.g. a driver airbag, a passenger airbag and/or a side airbag. US 6,161,070, to Jinno et al., relates to a passenger detection system including a single antenna electrode mounted on a surface of a passenger seat in an automobile. An oscillator applies on oscillating voltage signal to the antenna electrode, whereby a minute electric field is produced around the antenna electrode. Jinno proposes detecting the presence or absence of a passenger in the seat based on the amplitude and the phase of the current flowing to the antenna electrode.

[0005] US 6,392,542 to Stanley teaches an electric field sensor comprising an electrode mountable within a seat and operatively coupled to a sensing circuit, which applies to the electrode an oscillating or pulsed signal having a frequency "at most weakly responsive" to wetness of the seat. Stanley proposes to measure phase and amplitude of the current flowing to the electrode to detect an occupied or an empty seat and to compensate for seat wetness.

[0006] Another example for the use of capacitive sensors in an automotive vehicle application is the so-called Hands on Detection (HoD) system, in which one or more sensors provide information about whether a driver has his hands on a steering wheel of a vehicle or not. This information can be transferred to an ADAS such as an Adaptive Cruise Control (ACC), which, based on the provided sensor signal, can alert the driver and remind him or her to take control of the steering wheel again. In particular, such HoD systems can be used in support to fulfill a requirement of the Vienna convention that the driver must remain in control of the vehicle at all times. HoD systems may as well be employed in a parking assistance system or an ADAS that is configured for evaluating a driver activity at high speed.

[0007] In some (so-called "loading mode") capacitive sensors, the at least one antenna electrode serve at the same time as sensing electrode. In this case, a measurement circuit determines a current flowing into the at least one antenna electrode in response to an oscillating voltage being applied to them. The relationship of voltage to current yields the complex impedance between the at least one antenna electrode and ground potential. In an alternative version of capacitive sensors ("coupling mode" capacitive sensors), the transmitting antenna electrode(s) and the sensing electrode(s) are separate from one another. In this case, the measurement circuit determines a current or voltage that is induced in the sensing electrode when at least one transmitting antenna electrode is being operated.

[0008] Different capacitive sensing mechanisms are for instance explained in the technical paper entitled "*Electric Field Sensing for Graphical Interfaces*" by J. R. Smith et al., published in IEEE Computer Graphics and Applications, 18(3): 54-60, 1998, which shall hereby be incorporated by reference in its entirety with effect for the jurisdictions permitting incorporation by reference.

[0009] The paper describes the concept of electric field sensing as used for making non-contact three-dimensional position measurements, and more particularly for sensing the position of a human hand for purposes of providing three dimensional positional inputs to a computer. Within the general concept of capacitive sensing, the author distinguishes between distinct mechanisms he refers to as "loading mode", "shunt mode", and "transmit mode" which correspond to various possible electric current pathways. In the "loading mode", an oscillating voltage signal is applied to a transmit electrode, which builds up an oscillating electric field to ground. The object to be sensed modifies the capacitance between the transmit electrode and ground. In the "shunt mode", which is alternatively referred to as "coupling mode", an oscillating voltage signal is applied to the transmitting electrode, building up an electric field to a receiving electrode, and the displacement current induced at the receiving electrode is measured. The measured displacement current depends on the body being sensed. In the "transmit mode", the transmit electrode is put in contact with the user's body, which then becomes a transmitter relative to a receiver, either by direct electrical connection or via capacitive coupling.

[0010] The capacitive coupling strength may, for instance, be determined by applying an alternating voltage signal to an antenna electrode and by measuring the current flowing from that antenna electrode either towards ground (in the loading mode) or into a second antenna electrode (in the coupling mode). This current may be measured by a transimpedance amplifier, which is connected to the sensing electrode and which converts the current flowing into the sensing electrode into a voltage proportional to this current.

[0011] Some capacitive sensors are designed as sense-only capacitive sensors having a single sense electrode. Also, quite often capacitive sensors are used that comprise a sense electrode and a so-called "guard electrode" that are proximally arranged and mutually insulated from each other. This technique of "guarding" is well known in the art and is frequently used for intentionally masking, and thus shaping, a sensitivity regime of a capacitive sensor. To this end, the guard electrode is kept at the same electric AC potential as the sense electrode. As a result, a space between the sense electrode and the guard electrode is free of an electric field, and the guard-sense capacitive sensor is insensitive in a direction between the sense electrode and the guard electrode.

[0012] Capacitive sensors, which use a heating member as antenna electrode, are also known in the patent literature.

[0013] This is illustrated, by way of example, in US 2011/0148648 A1, which describes a capacitive occupant sensing system for a vehicle seat. An electrode is arranged in a seat proximate to an expected location of an occupant for sensing an occupant proximate thereto. The electrode may be integrated with a seat heater. A control circuitry controls the seat heater. A signal generator is coupled to the electrode and configured to output to the electrode a plurality of signals at a plurality of frequencies. Occupant detection circuitry detects voltages responsive to the plurality of signals at the plurality of frequencies and detects a state of occupancy based on the detected voltages. An LC circuit coupled to the electrode and the control circuitry suppresses capacitance generated by the control circuitry. The LC circuit may include a common mode choke to suppress the effects of external capacitance influences.

[0014] WO 92/17344 A1 describes an electrically heated vehicle seat with a conductor, which can be heated by the passage of electrical current, and which is located in the seating surface, wherein the conductor also forms one electrode of a two-electrode seat occupancy sensor.

[0015] WO 95/13204 A1 discloses a similar system, in which the oscillation frequency of an oscillator connected to the heating element is measured to derive the occupancy state of the vehicle seat. More elaborate combinations of a seat heater and a capacitive sensor are disclosed, for instance, in US 7,521,940 B2, US 2009/0295199 A1 and US 6,703,845.

[0016] US 6,703,845 B2 describes an occupant sensor. An oscillatory or pulsed first signal is applied to a seat heating element that is operatively connected to first and second impedances that isolate the first signal from the source and sink of power to the heating element. In another embodiment, third and fourth impedances are connected to the first and second impedances at respective nodes, and a second signal substantially equal to the first signal is operatively coupled to the nodes. In another embodiment, the first signal is applied to an electrode, and the second signal is applied to the heating element, which shields the electrode from influence by the seat. In another embodiment, the first signal is applied to a first electrode that is shielded from the heating element by a second electrode operatively coupled to the second signal. The impedances may, for example, be provided by inductors or electronic switches.

Object of the invention

[0017] In many applications of capacitive sensing devices, an installation of at least one sense electrode and a guard electrode in the vicinity of a heating member at tight conditions can be laborious and, thus, labor- and cost-intensive. Furthermore, the sense-guard electrode assembly may interfere with the intended proper function of the heating member.

[0018] It is therefore an object of the invention to provide a capacitive sensing device that enables capacitive measurements with the benefits of a guard electrode in the presence of a heating member, that has a less complex design and that is undisturbing to a desired function of the heating member, and to provide a method of operating such capacitive sensing device.

General Description of the Invention

[0019] In one aspect of the present invention, the object is achieved by a capacitive sensing device that comprises a capacitive sensor having at least one electrically conductive sense electrode and at least one electrically conductive guard electrode that are proximal arranged to and mutually insulated from each other, wherein the at least one guard electrode is designed as an electric heating member. The capacitive sensing device further includes a periodic signal voltage source that is configured for providing a periodic electrical measurement signal with reference to a reference voltage at an output port that is electrically connected to the at least one sense electrode and to the at least one guard electrode.

[0020] A complex impedance measurement circuit of the capacitive sensing device is electrically connected to the output port of the periodic signal voltage source and to the at least one sense electrode. The complex impedance measurement circuit is configured for measuring complex sense currents generated in the at least one sense electrode, and for determining a complex impedance based on the measured complex sense current.

[0021] Furthermore, the capacitive sensing device includes an AC decoupling circuit that has an input interface that is electrically connectable to an electric heater power unit, and that has an output interface that is electrically connected to ends of the at least one guard electrode for providing electric power to the at least one guard electrode.

[0022] The phrase "being configured to", as used in this application, shall in particular be understood as being specifically programmed, laid out, furnished or arranged. The term "electrically connected", as used in this application, shall be understood as a galvanic electrical connection or an electrical connection that is established by capacitive and/or inductive electromagnetic coupling.

[0023] It is further noted herewith that the terms "first", "second", etc. are used in this application for distinction purposes only, and are not meant to indicate or anticipate a sequence or a priority in any way.

[0024] The capacitive sensing device disclosed herein allows for guarded capacitive measurements that are undisturbed by the presence of a heating member. Due to the double function of the guard electrode (guarding/heating), the design of the capacitive sensing device can be simplified, and the omission of a separate guard electrode can facilitate an easier and faster installation. Moreover, an intended proper function of the heating member is unaffected due to the double function of the guard electrode.

[0025] The invention is, without being limited to, in particular beneficially employable in automotive applications using capacitive sensing, particularly in hands-on detection systems and seat occupancy detection and/or classification systems, but may as well be used in any other technical field in which a capacitive sensing device with a guard electrode is used in combination with an electric heater member. The term “automotive”, as used in this patent application, shall particularly be understood as being suitable for use in vehicles including passenger cars, trucks, semi-trailer trucks and buses.

[0026] The electric heater power unit may be designed as a DC power source, but may generally also be designed to output a time-varying electric power having a fundamental frequency that is much lower than a fundamental frequency of the periodic signal voltage source. The term “much lower”, as used in this application, shall be understood as a factor of more than 100 (i.e. more than two orders of magnitude), preferably more than three orders of magnitude, and, most preferably, more than four orders of magnitude. The term “fundamental frequency”, as used in this application, shall particularly be understood as a lowest sinusoidal frequency in a Fourier analysis of the respective time-varying output signal.

[0027] The complex impedance measurement circuit may include at least one transimpedance amplifier.

[0028] In preferred embodiments, the capacitive sensing device further comprises an electronic control unit, which the periodic signal voltage source and the complex impedance measurement circuit form an integral part of, and that comprises a processor unit and a digital data memory unit to which the processor unit has data access. The phrase “integral part of”, as used in this application, shall particularly encompass that the electronic control unit, the periodic signal voltage source and the complex impedance measurement circuit share a common circuitry and/or share a common housing. In this way, a compact design of the capacitive sensing device can be provided. Besides the savings of hardware parts, a fast and undisturbed, low-noise processing of signals within the operatively connected units can be accomplished.

[0029] Preferably, the at least one sense electrode and the at least one guard electrode each comprise at least one flexible film, which substantially have a same area size and, in an operational state, are arranged in parallel to each other. This can allow for a compact and flexible arrangement of the at least one sense electrode and the at least one guard electrode, which can be beneficial in many applications of the capacitive sensing device.

[0030] In preferred embodiments of the capacitive sensing device, the AC decoupling circuit comprises at least one common mode choke, wherein an input side of the common mode choke is electrically connected to the input interface and an output side of the common mode choke is electrically connected to the output interface of the AC decoupling circuit.

[0031] Common mode chokes may include at least two wire windings, which may have a same number of turns, and are wound on a common core. The common core may e.g. be a ferrite core or a core made of any other core material which has an influence on the magnetic flux/permeability. The at least two wire windings work as simple wires against differential mode current, such as an electric current provided to the at least one electric heating member by the electric heater power unit, flowing through the common mode choke windings in opposite current directions. Against common mode current flowing through the common mode choke windings in the same current direction, the at least two wire windings work as one inductor having a large impedance. In this way, a virtual AC-decoupling of the at least one electric heating member and the electric heater power unit can be accomplished by the common mode choke, which can allow for an undisturbed provision of the periodic electrical measurement signal to the at least one guard electrode.

[0032] In preferred embodiments of the capacitive sensing device, the AC decoupling circuit comprises at least two discrete inductors. One inductor each of the at least two discrete inductors is electrically connected between one input port of the input interface and one output port of the output interface of the AC decoupling circuit. The term “discrete inductors”, as used in this application, shall be understood as two separate inductors that are intended to not magnetically couple with each other.

[0033] The at least two discrete inductors can be designed to have a large impedance at a fundamental frequency of the periodic electrical measurement signal, while at the same time they have a low impedance for an electric current provided by the electric heater power unit to the at least one guard electrode. By making use of the large difference in impedance of the discrete inductors at the two relevant frequencies, an AC-decoupling of the at least one electric heating member and the electric heater power unit can be accomplished by the discrete inductors, which can allow for an undisturbed provision of the periodic electrical measurement signal to the at least one guard electrode.

[0034] In preferred embodiments of the capacitive sensing device, the AC decoupling circuit comprises at least two remote-controllable switch members, wherein each remote-controllable switch member is configured to make or break an electric connection between one input port of the input interface and one output port of the output interface of the AC decoupling circuit.

[0035] In this way, an AC-decoupling and a galvanic disconnection of the at least one electric heating member and the electric heater power unit can be accomplished. By that, an undisturbed provision of the periodic electrical measurement signal to the at least one guard electrode may be achieved.

[0036] Preferably, the capacitive sensing device further comprises a switch remote control unit that is at least configured for controlling the at least two remote-controllable switch members. In this way, a reliable and automatic execution of a capacitive measurement by the complex impedance measurement circuit with the electric heater power unit being AC-decoupled and galvanically disconnected from the at least one guard electrode can be facilitated.

[0037] Preferably, the switch remote control unit forms part of the electronic control unit.

[0038] Preferably, the electronic control unit comprises a processor unit that forms an integral part of a microcontroller. Microcontrollers that are suitably equipped and include, for instance, a processor unit, a digital data memory unit, a microcontroller system clock, a multiplexer unit and analog-to-digital converters are nowadays readily available in many variations.

[0039] In preferred embodiments of the capacitive sensing device, the periodic electrical measurement signal has a fundamental frequency that lies in a range between 10 kHz and 100 MHz. By that, a layout of the complex impedance measurement circuit can be enabled that is balanced between a hardware and cost effort and a sensitivity required by the specific application.

[0040] Preferably, the periodic electrical measurement signal is formed as a sinusoidal signal. By that, a portion of higher harmonics of the periodic electric measurement signal, which potentially may overcome the AC decoupled circuit can be kept low from the beginning.

[0041] In another aspect of the invention, a hands-on or hands-off detection device for a heatable steering wheel, in particular for a vehicle, is provided. The hands-on or hands-off detection device comprises a capacitive sensing device as disclosed herein, wherein the at least one heating member is arranged on a rim, in particular a major part of a rim, of the steering wheel. The hands-on or hands-off detection device further includes an electric heater power unit that is connectable to the at least one guard electrode, for providing electric heating power.

[0042] The benefits described in context with the capacitive sensing device applied to the hands-on/hands-off detection device to the full extent.

[0043] In yet another aspect of the invention, a seat occupancy detection system for detecting an occupancy of a heatable seat, in particular for a vehicle, is provided. The seat occupancy detection system comprises a capacitive sensing device as disclosed herein, wherein the at least one heating member is arranged at a cushion or a backrest formed part of the seat. The seat occupancy detection system further includes an electric heater power unit that is connectable to the at least one guard electrode for providing electric heating power.

[0044] The benefits described in context with the capacitive sensing device applied to the seat occupancy detection system to the full extent.

[0045] In yet a further aspect of the invention, a method for determining a complex impedance of a guard-sense capacitive sensor, using a capacitive sensing device as described herein is provided.

[0046] The method includes at least the following steps, which are to be carried out in an iterative manner:

- by control of the switch remote control unit, transfer the at least two remote-controllable switch members into an open state for electrically disconnecting the electric heater power unit from the at least one guard electrode,
- by operating the periodic signal voltage source, provide a periodic electrical measurement signal with reference to a reference voltage to the at least one sense electrode and to the at least one guard electrode,
- by operating the complex impedance measurement circuit, measure a

complex sense current generated in the at least one sense electrode,

- by operating the complex impedance measurement circuit, determine a complex impedance based on the measured complex sense current, and
- by control of the switch remote control unit, transfer the at least two remote-controllable switch members into a closed state for electrically connecting the electric heater power unit to the at least one guard electrode.

[0047] In preferred embodiments of the method, a first time period between the step of transferring the at least two remote-controllable switch members into an open state and the step of transferring the at least two remote-controllable switch members into a closed state is small in comparison to a second time period between the step of transferring the at least two remote-controllable switch members into a closed state and a next successive step of transferring the at least two remote-controllable switch members into an open state.

[0048] In this way, an average availability of the heating function of the at least one guard electrode can kept high and measurements at a satisfying rate by the complex impedance measurement circuit in a sense-guard manner can be accomplished.

[0049] Preferably, a ratio of the second time period to the first time period is larger than 10, more preferably larger than 20, and, most preferably, larger than 50.

[0050] In a further aspect of the invention, a software module for controlling an automatic execution of steps of an embodiment of the method disclosed herein is provided.

[0051] The method steps to be conducted are converted into a program code of the software module, wherein the program code is implementable in a digital data memory unit of the capacitive sensing device and is executable by a processor unit of the capacitive sensing device. Preferably, the digital data memory unit and/or processor unit may be a digital data memory unit and/or a processing unit of the electronic control unit of the capacitive sensing device. The processor unit may, alternatively or supplementary, be another processor unit that is especially assigned to execute at least some of the method steps.

[0052] The software module can enable a robust and reliable, automatic execution of the method and can allow for a fast modification of method steps.

[0053] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

[0054] It shall be pointed out that the features and measures detailed individually in the preceding description can be combined with one another in any technically meaningful manner and show further embodiments of the invention. The description characterizes and specifies the invention in particular in connection with the figures.

Brief Description of the Drawings

[0055] Further details and advantages of the present invention will be apparent from the following detailed description of not limiting embodiments with reference to the attached drawings, wherein:

Fig. 1 schematically shows a vehicle seat equipped with a seat occupancy detection system comprising a possible embodiment of a capacitive sensing device in accordance with the invention, in an installed state;

Fig. 2 shows a more detailed layout of the capacitive sensing device pursuant to Fig. 1;

Fig. 3 shows a layout of the seat occupancy detection system pursuant to Fig. 1 comprising an alternative possible embodiment of a capacitive sensing device in accordance with the invention;

Fig. 4 shows a layout of the seat occupancy detection system pursuant to Fig. 1 comprising another alternative possible embodiment of a capacitive sensing device in accordance with the invention;

Fig. 5 is a flowchart of an embodiment of a method in accordance with the invention of operating the capacitive sensing device pursuant to Fig. 4; and

Fig. 6 schematically shows a steering wheel with an installed capacitive hands-on or hands-off sensing system equipped with a possible embodiment of a capacitive sensor device in accordance with the invention.

Description of Preferred Embodiments

[0056] Fig. 1 schematically shows a seat 88 equipped with a seat occupancy detection system 10 comprising a possible embodiment of a capacitive sensing device 12 in accordance with the invention, in an installed state and in a side view. The seat 88 is designed as a vehicle seat of a passenger car and includes a seat structure (not shown) by which it is erected on a passenger cabin floor of the passenger car, as is well known in the art.

[0057] The seat 88 further includes a seat base 90 supported by the seat structure and configured for receiving a seat cushion 92 for providing comfort to a seat occupant. The seat cushion 92 of the vehicle seat comprises a seat foam member and a fabric cover, which has been omitted in Fig. 1. The seat base 90 and the seat cushion 92 are provided for supporting a bottom of the seat occupant. A backrest 94 of the seat 88 is provided for supporting a back of the seat occupant.

[0058] The seat occupancy detection system 10 is configured for detecting an occupancy of a heatable seat 88, in particular a heatable vehicle seat 88 of a passenger car, and further comprises an electric heater power unit 50, which in this specific embodiment is fed by a starter battery of the vehicle.

[0059] The capacitive sensing device 12 includes a capacitive sensor 14 comprising an electrically conductive sense electrode 16 and an electrically conductive guard electrode 18 that are proximal arranged to and mutually insulated from each other.

[0060] The electrically conductive sense electrode 16 and the electrically conductive guard electrode 18 are located on the A-surface of the seat cushion 92, underneath the fabric cover. The sense electrode 16 and the guard electrode 18 substantially have an identical footprint with regard to the A-surface of the seat cushion 92. The sense electrode 16 is arranged above the guard electrode 18, i.e. closer to a potential seat occupant, and the sense electrode 16 and the guard electrode 18 are arranged substantially parallel to the A-surface.

[0061] The guard electrode 18 is designed as an electric heating member. Electric heating members for vehicles are well known in the art and therefore do not have to be described in detail herein.

[0062] Besides the capacitive sensor 14, the capacitive sensing device 12 further includes an electronic control unit 20 and an AC decoupling circuit 34. Fig. 2 shows a more detailed layout of the capacitive sensing device 12 pursuant to Fig. 1.

[0063] The AC decoupling circuit 34 has an input interface 36 that is electrically connected to the electric heater power unit 50, and an output interface 38 that is electrically connected to ends of the guard electrode 18, for providing electric power to the guard electrode 18 to function as a heating member for the vehicle seat 88.

[0064] The electronic control unit 20 comprises a periodic signal voltage source 24, a complex impedance measurement circuit 26, a processor unit 28 and a digital data memory unit 30 to which the processor unit 28 has data access. The periodic signal voltage source 24, the complex impedance measurement circuit 26, the processor unit 28 and the digital memory unit 30 form integral parts of the electronic control unit 20 and share a common housing and parts of the circuitry. An output port 22 of the electronic control unit 20 is connected to an airbag control unit 98 of the vehicle.

[0065] The periodic signal voltage source 24 is configured for providing a periodic electrical measurement signal, with reference to a reference voltage, at an output port 32 that is electrically connected to the guard electrode 18 and via the complex impedance measurement circuit 26 to the sense electrode 16. In this specific embodiment, the periodic signal voltage source provides a sinusoidal periodic electrical measurement signal with a fundamental frequency of e.g. 20 MHz. The fundamental frequency may typically lie in a range between 10 kHz and 100 MHz.

[0066] A first capacitor 46 is provided across the electric heater power unit 50 to ensure an AC ground at the input interface 36 of the AC decoupling circuit 34. A second capacitor 48 is provided across the guard electrode 18 to provide the periodic electrical measurement signal to both ends of the guard electrode 18.

[0067] The complex impedance measurement circuit 26 is electrically connected to the output port 32 of the periodic signal voltage source 24 and to the sense electrode 16, and is configured for measuring complex sense currents generated in the sense electrode 16. To this end, the complex impedance measurement circuit 26 includes sense current measurement means (not shown) that may include at least one transimpedance amplifier. The complex impedance measurement circuit 26 is further configured for determining a complex impedance based on the measured complex sense current and a voltage measured at the output port 32 of the periodic signal voltage source 24.

[0068] Moreover, the seat occupancy detection system 10 comprises a controllable pulse-width modulation (PWM) switching unit 52 for controlling a provision of electric heating power to the guard electrode 18. In this specific embodiment, the provision of electric heating power from the heating power source 51 is controllable by the electronic control unit 20 via the PWM switching unit 52. A typical switching frequency of a PWM scheme may typically lie in a range between 10 and 100 Hz; the switching frequency may be for example 25 Hz.

[0069] The AC decoupling circuit 34 comprises a common mode choke 40. An input side 42 of the common mode choke 40 is electrically connected to the input interface 36. An output side 44 of the common mode choke 40 is electrically connected to the output interface 38 of the AC decoupling circuit 34.

[0070] The common mode choke 40 provides a virtual AC-decoupling of the guard electrode 18; i.e. the electric heating member, from the electric heater power unit 50. This allows for an undisturbed provision of the periodic electrical measurement signal to the guard electrode 18 for carrying out a capacitive measurement, while the electric heating member, i.e. the guard electrode 18, is being provided with electric power by the electric heater power unit 50.

[0071] In this specific embodiment, the capacitive sensor 12 is operated in loading mode. In general, it is also contemplated within the scope of the invention to operate a capacitive sensor in transmit mode or in shunt mode in some embodiments or in some modes of operation.

[0072] Fig. 3 shows a layout of the seat occupancy detection system 10 pursuant to Figs. 1 and 2 comprising an alternative possible embodiment of a capacitive sensing device 54 in accordance with the invention. In order to avoid unnecessary repetitions, only differences with respect to the first embodiment of a capacitive sensing device 12 pursuant to Fig. 2 will be described. For features in Fig. 3 that are not described, reference is made herewith to the description of the first embodiment.

[0073] Instead of a common mode choke, an AC decoupling circuit 56 of the alternative capacitive sensing device 54 comprises two discrete inductors 58, 60. Each one of the two discrete inductors 58, 60 is electrically connected between one input port of the input interface 36 and one output port of the output interface 38 of the AC decoupling circuit 56. The two inductors 58, 60 provide a virtual AC-decoupling of the guard electrode 18; i.e. the electric heating member, from the electric heater power unit 50. This allows for an undisturbed provision of the periodic electrical measurement signal to the guard electrode 18 for carrying out a capacitive measurement, while the electric heating member, i.e. the guard electrode 18, is being provided with electric power by the electric heater power unit 50.

[0074] Fig. 4 shows a layout of the seat occupancy detection system 10 pursuant to Figs. 1 and 2 comprising another alternative possible embodiment of a capacitive sensing device 62 in accordance with the invention. In order to avoid unnecessary repetitions, again only differences with respect to the first embodiment pursuant to Fig. 1 will be described. For features in Fig. 4 that are not described, reference is made herewith to the description of the first embodiment.

[0075] Instead of a common mode choke, the AC decoupling circuit 64 of the second alternative capacitive sensing device 62 comprises two remote-controllable switch members 66, 68. Each one of the remote-controllable switch members 66, 68 is configured to make or break an electric connection between one input port of the input interface 36 and one output port of the output interface 38 of the AC decoupling circuit 64. The capacitive sensing device 62 comprises a switch remote control unit 70 that is configured for controlling the two remote-controllable switch members 66, 68.

[0076] With both the remote-controllable switch members 66, 68 in a “break” position, an AC-decoupling and a galvanic disconnection of the guard electrode 18; i.e. the electric heating member, from the electric heater power unit 50 is provided. The periodic electrical measurement signal can be fed to the guard electrode 18 in an undisturbed manner.

[0077] In the following, an embodiment of a method for determining a complex impedance of a guard-sense capacitive sensor 14 operated in loading mode using the embodiment of a capacitive sensing device 62 pursuant to Fig. 4 will be described with reference to Fig. 4 and Fig. 5, which provides a flowchart of a method. In preparation of operating the capacitive sensing device 62, it shall be understood that all involved units and devices are in an operational state and configured as illustrated in Fig. 4.

[0078] In order to be able to carry out the method automatically and in a controlled way, the electronic control unit 20 comprises a software module 96. The method steps to be conducted are converted into a program code of the software module 96. The program code is implemented in the digital data memory unit 30 of the electronic control unit 20 and is executable by the processor unit 28 of the electronic control unit 20.

[0079] Execution of the method may be initiated by turning on the passenger car ignition. As indicated in Fig. 5, the steps of the method are automatically carried out in an iterative manner.

[0080] In a first step 100 of the method, by control of the switch remote control unit 70, the two remote-controllable switch members 66, 68 are transferred into an open (= “break”) state for electrically disconnecting the electric heater power unit 50 from the guard electrode 18. In a next step 102, by operating the periodic signal voltage source 24, a periodic electrical measurement signal is provided with reference to a reference voltage to the sense electrode 16 and to the guard electrode 18. Then in another step 104, by operating the complex impedance measurement circuit 26, a complex sense current generated in the sense electrode 16 is measured. By operating the complex impedance measurement circuit 26, a complex impedance based on the measured complex sense current is determined in a next step 106 of the method.

[0081] By control of the switch remote control unit 70, the two remote-controllable switch members 66, 68 are transferred into a closed (= “make”) state for electrically connecting the electric heater power unit 50 to the guard electrode 18, i.e. the electric heating member, and the capacitive sensing device 62 is ready for the next iteration of methods steps.

[0082] In this specific embodiment of the method, the timing of transferring the two remote-controllable switch members 66, 68 between the open state and the closed state is performed such that a time period between the step 100 of transferring the two remote-controllable switch members 66, 68 into the open state and the step 108 of transferring the two remote-controllable switch members 66, 68 into the closed state is small in comparison to a time period between the step 108 of transferring the two remote-controllable switch members 66, 68 into the closed state and a next successive step 100 of transferring the two remote-controllable switch members 66, 68 into the open state.

[0083] Fig. 6 shows a layout of a capacitive hands-on detection system 72 for a heatable steering wheel 74 of a vehicle. The capacitive hands-on detection system 72 comprises an alternative embodiment of a capacitive sensing device 78 in accordance with the invention. In order to avoid unnecessary repetitions, only differences with respect to the first embodiment of a capacitive sensing device 12 pursuant to Figs. 1 and 2 will be described. For features in Fig. 6 that are not described, reference is made herewith to the description of the first embodiment of a capacitive sensing device 12 pursuant to Figs. 1 and 2.

[0084] In the alternative embodiment of a capacitive sensing device 78, a sense electrode 82 and a guard electrode 84 that is designed as an electric heating member each comprise a flexible film or any another suitable isolating carrier material, which substantially have a same area size. The flexible film of the sense electrode 82 may be equipped with a continuous layer 86 of an electrically conductive material that substantially covers the complete area of the flexible film. The flexible film of the guard electrode 84 may be equipped with one or more continuous lines 80 of an electrically resistive material meandering across a major part of the area of the flexible film (only hinted in Fig. 6). In an installed and operational state, the sense electrode 82 and the guard electrode 84 are arranged in parallel to each other, and are wound around and arranged on a major part of a rim 76 of the steering wheel 74.

[0085] While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments.

[0086] Other variations to be disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word “comprising” does not exclude other elements or steps, and the indefinite article “a” or “an” does not exclude a plurality, which is meant to express a quantity of at least two. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting scope.

List of Reference Symbols

10 seat occupancy detection system
12 capacitive sensing device
14 capacitive sensor
16 sense electrode
18 guard electrode (electric heating member)
20 electronic control unit
22 output port
24 periodic signal voltage source
26 complex impedance measurement circuit
28 processor unit
30 digital data memory unit
32 output port
34 AC decoupling circuit
36 input interface
38 output interface
40 common mode choke
42 input side
44 output side
46 first capacitor
48 second capacitor
50 electric heater power unit
51 heating power source
52 PWM switching unit
54 capacitive sensing device
56 AC decoupling circuit
58 discrete inductor
60 discrete inductor
62 capacitive sensing device
64 AC decoupling circuit
66 remote-controllable switch member
68 remote-controllable switch member
70 switch remote control unit
72 hands-on detection device
74 heatable steering wheel
76 rim
78 capacitive sensing device
80 electrically resistive material line
82 sense electrode
84 guard electrode
86 continuous electrically conductive material layer
88 seat
90 seat base
92 seat cushion
94 backrest
96 software module
98 airbag control unit

Method steps:

100 transfer remote-controllable switch members to “break” state
102 provide periodic electrical measurement signal to sense electrode and guard electrode
104 measure complex sense current in sense electrode

Claims

1. A capacitive sensing device (12; 54; 62; 78), comprising
   - a capacitive sensor (14) having at least one electrically conductive sense electrode (16) and at least one electrically conductive guard electrode (18; 84) that are proximal arranged to and mutually insulated from each other, wherein the at least one guard electrode (18; 84) is designed as an electric heating member,
   - a periodic signal voltage source (24) that is configured for providing a periodic electrical measurement signal with reference to a reference voltage at an output port (32) that is electrically connected to the at least one sense electrode (16) and to the at least one guard electrode (18; 84),
   - a complex impedance measurement circuit (26) that is electrically connected to the output port (32) of the periodic signal voltage source (24) and to the at least one sense electrode (16), and that is configured for measuring complex sense currents generated in the at least one sense electrode (16), and for determining a complex impedance based on the measured complex sense current, and
   - an AC decoupling circuit (34; 56; 64) having an input interface (36) that is electrically connectable to an electric heater power unit (50), and an output interface (38) that is electrically connected to ends of the at least one guard electrode (18; 84) for providing electric power to the at least one guard electrode (18; 84).

2. The capacitive sensing device (12; 54; 62; 78) as claimed in claim 1, further comprising an electronic control unit (20), which the periodic signal voltage source (24) and the complex impedance measurement circuit (26) form an integral part of, and that comprises a processor unit (28) and a digital data memory unit (30) to which the processor unit (28) has data access.

3. The capacitive sensing device (78) as claimed in claim 1 or 2, wherein the at least one sense electrode (82) and the at least one guard electrode (84) each comprise at least one flexible film, which substantially have same area size and, in an operational state, are arranged in parallel to each other.

4. The capacitive sensing device (12) as claimed in any one of claims 1 to 3, wherein the AC decoupling circuit (34) comprises at least one common mode choke (40), wherein an input side (42) of the common mode choke (40) is electrically connected to the input interface (36) and an output side (44) of the common mode choke (40) is electrically connected to the output interface (38) of the AC decoupling circuit (34).

5. The capacitive sensing device (54) as claimed in any one of claims 1 to 3, wherein the AC decoupling circuit (56) comprises at least two discrete inductors (58, 60), wherein one each of the at least two discrete inductors (58, 60) is electrically connected between one input port of the input interface (36) and one output port of the output interface (38) of the AC decoupling circuit (56).

6. The capacitive sensing device (62; 78) as claimed in any one of claims 1 to 3, wherein the AC decoupling circuit (64) comprises at least two remote-controllable switch members (66, 68), wherein each remote-controllable switch member (66, 68) is configured to make or break an electric connection between one input port of the input interface (36) and one output port of the output interface (38) of the AC decoupling circuit (64).

7. The capacitive sensing device (62; 78) as claimed in claim 6, further comprising a switch remote control unit (70) that is at least configured for controlling the at least two remote-controllable switch members (66, 68).

8. The capacitive sensing device (12; 54; 62; 78) as claimed in any one of the preceding claims, wherein the periodic electrical measurement signal has a fundamental frequency that lies in a range between 10 kHz and 100 MHz.

9. A hands-on or hands-off detection device (72) for a heatable steering wheel (74), comprising

   - a capacitive sensing device (78) as claimed in any one of claims 1 to 8, wherein the at least one heating member is arranged on a rim (76) of the steering wheel (74),
   - an electric heater power unit (50) that is connectable to the at least one guard electrode (84), for providing electric heating power.

10. A seat occupancy detection system (10) for detecting an occupancy of a heatable seat (88), in particular a vehicle seat, the seat occupancy detection system (10) comprising

    - a capacitive sensing device (12; 54; 62) as claimed in any one of claims 1 to 8, wherein the at least one heating member is arranged at a cushion (92) or a backrest (94) forming part of the seat (88), and
    - an electric heater power unit (50) that is connectable to the at least one guard electrode (18) for providing electric heating power.

11. A method for determining a complex impedance of a guard-sense capacitive sensor (14) using a capacitive sensing device (62; 78) as claimed in claim 7, the method including at least the following steps, which are to be carried out in an iterative manner:

    - by control of the switch remote control unit (70), transfer (100) the at least two remote-controllable switch members (66, 68) into an open state for electrically disconnecting the electric heater power unit (50) from the at least one guard electrode (18; 84),
    - by operating the periodic signal voltage source (24), provide (102) a periodic electrical measurement signal with reference to a reference voltage to the at least one sense electrode (16; 82) and to the at least one guard electrode (18; 84),
    - by operating the complex impedance measurement circuit (26), measure (104) a complex sense current generated in the at least one sense electrode (16; 82),
    - by operating the complex impedance measurement circuit (26), determine (106) a complex impedance based on the measured complex sense current, and
    - by control of the switch remote control unit (70), transfer (108) the at least two remote-controllable switch members (66, 68) into a closed state for electrically connecting the electric heater power unit (50) to the at least one guard electrode (18; 84).

12. The method as claimed in claim 11, wherein a time period between the step of transferring (100) the at least two remote-controllable switch members (66, 68) into an open state and the step of transferring (108) the at least two remote-

controllable switch members (66, 68) into a closed state is small in comparison to a time period between the step of transferring (108) the at least two remote-controllable switch members (66, 68) into a closed state and a next successive step of transferring (100) the at least two remote-controllable switch members (66, 68) into an open state.

13. A software module (96) for automatically carrying out the method as claimed in claim 11 or 12, wherein the method steps to be conducted are converted into a program code of the software module (96), wherein the program code is implementable in a digital data memory unit (30) of the capacitive sensing device (12; 54; 62; 78) as claimed in any one of claims 2 to 8 or a separate control unit and is executable by a processor unit (28) of the capacitive sensing device (12; 54; 62; 78) as claimed in any one of claims 2 to 8 or a separate control unit.

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ANSPRÜCHE

1. Kapazitive Fühlvorrichtung (12; 54; 62; 78), umfassend
   - einen kapazitiven Sensor (14) mit mindestens einer elektrisch leitenden Fühlelektrode (16) und mindestens einer elektrisch leitenden Schutzelektrode (18; 84), die zueinander proximal angeordnet und voneinander isoliert sind, wobei die mindestens eine Schutzelektrode (18; 84) als elektrisches Heizelement ausgeführt ist,
   - eine periodische Signalspannungsquelle (24), die dafür ausgelegt ist, ein periodisches elektrisches Messsignal in Bezug auf eine Bezugsspannung an einem Ausgangsanschluss (32) bereitzustellen, der elektrisch an die mindestens eine Fühlelektrode (16) und die mindestens eine Schutzelektrode (18; 84) angeschlossen ist,
   - eine komplexe Impedanzmessschaltung (26), die elektrisch an den Ausgangsanschluss (32) der periodischen Signalspannungsquelle (24) und die mindestens eine Fühlelektrode (16) angeschlossen und dafür ausgelegt ist, komplexe Fühlströme zu messen, die in der mindestens einen Fühlelektrode (16) erzeugt werden, und basierend auf dem gemessenen komplexen Fühlstrom eine komplexe Impedanz zu bestimmen, und
   - eine Wechselstrom-Entkopplungsschaltung (34; 56; 64) mit einer Eingangsschnittstelle (36), die elektrisch an eine elektrische Heizer-Leistungseinheit (50) anschließbar ist, und einer Ausgangsschnittstelle (38), die an Enden der mindestens einen Schutzelektrode (18; 84) elektrisch angeschlossen ist, um der mindestens einen Schutzelektrode (18; 84) Elektroenergie zuzuführen.

2. Kapazitive Fühlvorrichtung (12; 54; 62; 78) nach Anspruch 1, ferner umfassend eine elektronische Steuereinheit (20), von der die periodische Signalspannungsquelle (24) und die komplexe Impedanzmessschaltung (26) einen festen Bestandteil bilden und die eine Prozessoreinheit (28)

und eine digitale Datenspeichereinheit (30) umfasst, auf die die Prozessoreinheit (28) Datenzugriff hat.

3. Kapazitive Fühlvorrichtung (78) nach Anspruch 1 oder 2, wobei die mindestens eine Fühlelektrode (82) und die mindestens eine Schutzelektrode (84) jeweils mindestens einen flexiblen Film umfassen, die im Wesentlichen die gleiche Bereichsgröße haben und im Betriebszustand parallel zueinander angeordnet sind.

4. Kapazitive Fühlvorrichtung (12) nach einem der Ansprüche 1 bis 3, wobei die Wechselstrom-Entkopplungsschaltung (34) mindestens eine Gleichtaktdrossel (40) umfasst, wobei eine Eingangsseite (42) der Gleichtaktdrossel (40) elektrisch an die Eingangsschnittstelle (36) angeschlossen ist und eine Ausgangsseite (44) der Gleichtaktdrossel (40) elektrisch an die Ausgangsschnittstelle (38) der Wechselstrom-Entkopplungsschaltung (34) angeschlossen ist.

5. Kapazitive Fühlvorrichtung (54) nach einem der Ansprüche 1 bis 3, wobei die Wechselstrom-Entkopplungsschaltung (56) mindestens zwei diskrete Induktoren (58, 60) umfasst, wobei jeweils einer der mindestens zwei diskreten Induktoren (58, 60) zwischen einem Eingangsanschluss der Eingangsschnittstelle (36) und einem Ausgangsanschluss der Ausgangsschnittstelle (38) der Wechselstrom-Entkopplungsschaltung (56) elektrisch angeschlossen ist.

6. Kapazitive Fühlvorrichtung (62; 78) nach einem der Ansprüche 1 bis 3, wobei die Wechselstrom-Entkopplungsschaltung (64) mindestens zwei fernsteuerbare Schalterelemente (66, 68) umfasst, wobei jedes ferngesteuerte Schalterelement (66, 68) dafür ausgelegt ist, eine elektrische Verbindung zwischen einem Eingangsanschluss der Eingangsschnittstelle (36) und einem Ausgangsanschluss der Ausgangsschnittstelle (38) der Wechselstrom-Entkopplungsschaltung (64) herzustellen oder zu unterbrechen.

7. Kapazitive Fühlvorrichtung (62; 78) nach Anspruch 6, ferner umfassend eine Schalter-Fernsteuereinheit (70), die zumindest dafür ausgelegt ist, die mindestens zwei fernsteuerbaren Schalterelemente (66, 68) zu steuern.

8. Kapazitive Fühlvorrichtung (12; 54; 62; 78) nach einem der vorhergehenden Ansprüche, wobei das periodische elektrische Messsignal eine Grundfrequenz aufweist, die in einem Bereich zwischen 10 kHz und 100 MHz liegt.

9. Vorrichtung (72) zur Erkennung einer Handberührung für ein heizbares Lenkrad (74), umfassend
   - eine kapazitive Fühlvorrichtung (78) nach einem der Ansprüche 1 bis 8, wobei das mindestens eine Heizelement auf einem Kranz (76) des Lenkrads (74) angeordnet ist,
   - eine elektrische Heizer-Leistungseinheit (50), die an die mindestens eine Schutzelektrode (84) anschließbar ist, um elektrische Heizenergie bereitzustellen.

10. Sitzbelegungserkennungssystem (10) zum Erkennen einer Belegung eines heizbaren Sitzes (88), insbesondere eines Fahrzeugsitzes, wobei das Sitzbelegungserkennungssystem (10) Folgendes umfasst:
    - eine kapazitive Fühlvorrichtung (12; 54; 62) nach einem der Ansprüche 1 bis 8, wobei das mindestens eine Heizelement an einem Polster (92) oder einer Rückenlehne (94), die Teil des Sitzes (88) bilden, angeordnet ist, und
    - eine elektrische Heizer-Leistungseinheit (50), die an die mindestens eine Schutzelektrode (18) anschließbar ist, um eine elektrische Heizenergie bereitzustellen.

11. Verfahren zum Bestimmen einer komplexen Impedanz eines kapazitiven Schutz-Fühl-Sensors (14) unter Verwendung einer kapazitiven Fühlvorrichtung (62; 78) nach Anspruch 7, wobei das Verfahren mindestens die folgenden Schritte umfasst, die iterativ auszuführen sind:

- durch Steuern der Schalter-Fernsteuereinheit (70), Überführen (100) der mindestens zwei fernsteuerbaren Schalterelemente (66, 68) in einen geöffneten Zustand zum elektrischen Abkoppeln der elektrischen Heizer-Leistungseinheit (50) von der mindestens einen Schutzelektrode (18; 84),
- durch Betreiben der periodischen Signalspannungsquelle (24), Bereitstellen (102) eines periodischen elektrischen Messsignals in Bezug auf eine Bezugsspannung für die mindestens eine Fühlelektrode (16; 82) und für die mindestens eine Schutzelektrode (18; 84),
- durch Betreiben der komplexen Impedanzmessschaltung (26), Messen (104) eines komplexen Fühlstroms, der in der mindestens einen Fühlelektrode (16; 82) erzeugt wird,
- durch Betreiben der komplexen Impedanzmessschaltung (26), Bestimmen (106) einer komplexen Impedanz basierend auf dem gemessenen komplexen Fühlstrom, und
- durch Steuern der Schalter-Fernsteuereinheit (70), Überführen (108) der mindestens zwei fernsteuerbaren Schalterelemente (66, 68) in einen geschlossenen Zustand zum elektrischen Anschließen der elektrischen Heizer-Leistungseinheit (50) an die mindestens eine Schutzelektrode (18; 84).

12. Verfahren nach Anspruch 11, wobei ein Zeitraum zwischen dem Schritt des Überführens (100) der mindestens zwei fernsteuerbaren Schalterelemente (66, 68) in einen geöffneten Zustand und dem Schritt des Überführens (108) der mindestens zwei fernsteuerbaren Schalterelemente (66, 68) in einen geschlossenen Zustand im Vergleich zu einem Zeitraum zwischen dem Schritt des Überführens (108) der mindestens zwei fernsteuerbaren Schalterelemente (66, 68) in einen geschlossenen Zustand und einem nächsten darauffolgenden Schritt des Überführens (100) der mindestens zwei fernsteuerbaren Schalterelemente (66, 68) in einen geöffneten Zustand klein ist.

13. Softwaremodul (96) zum automatischen Ausführen des Verfahrens nach Anspruch 11 oder 12, wobei die auszuführenden Verfahrensschritte in einen Programmcode des Softwaremoduls (96) umgewandelt sind, wobei der Programmcode in einer digitalen Datenspeichereinheit (30) der kapazitiven Fühlvorrichtung (12; 54; 62; 78) nach einem der Ansprüche 2 bis 8 oder einer separaten Steuereinheit implementierbar und von einer Prozessoreinheit (28) der kapazitiven Fühlvorrichtung (12; 54; 62; 78) nach einem der Ansprüche 2 bis 8 oder einer separaten Steuereinheit ausführbar ist.

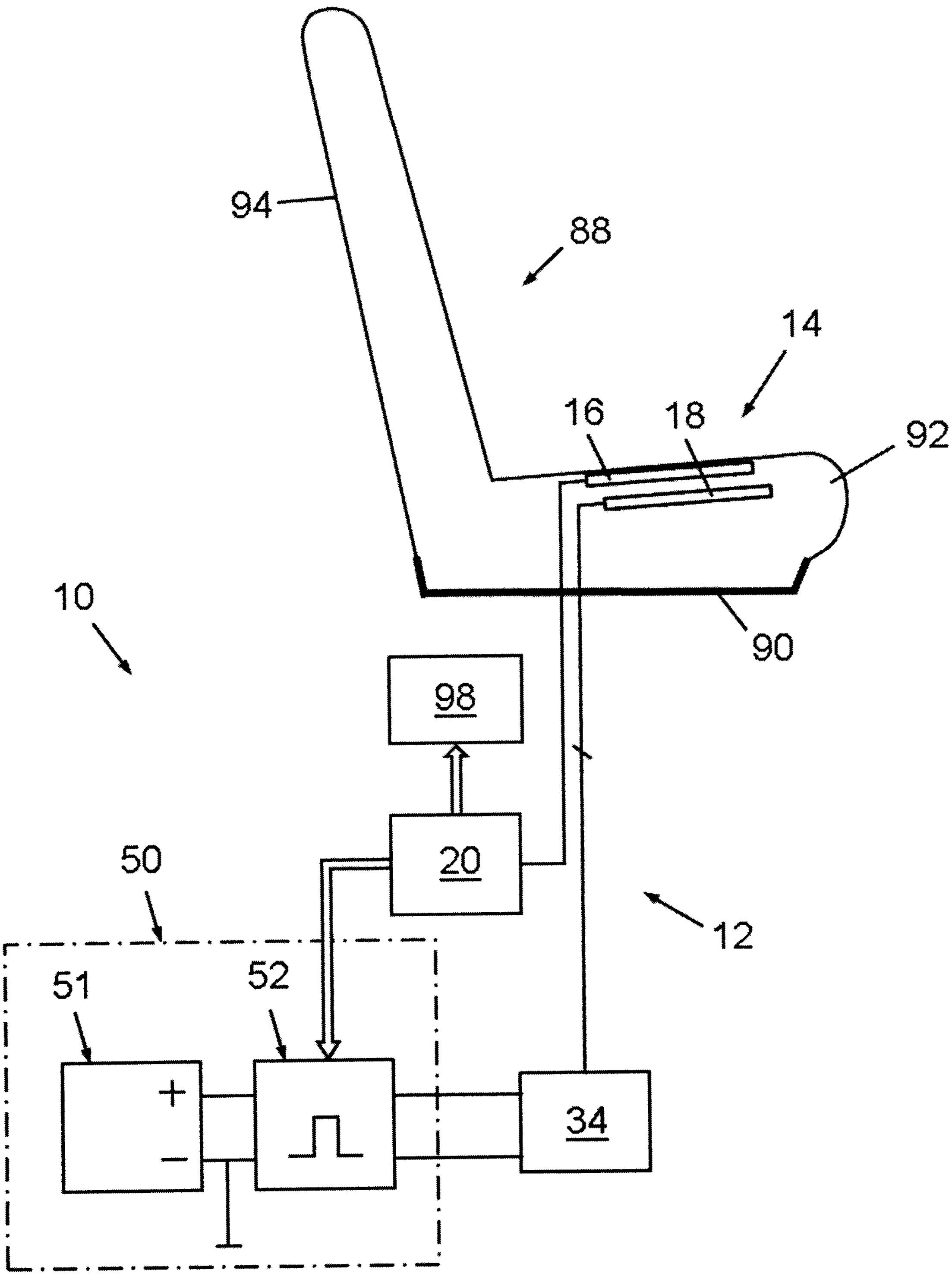
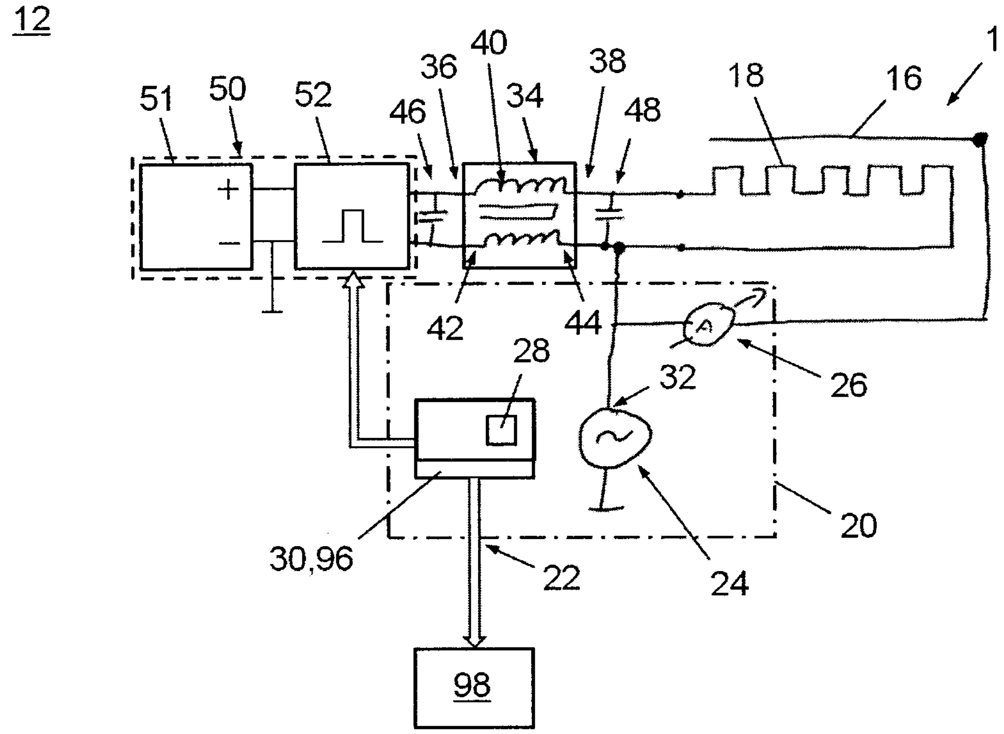


Fig. 1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40
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42
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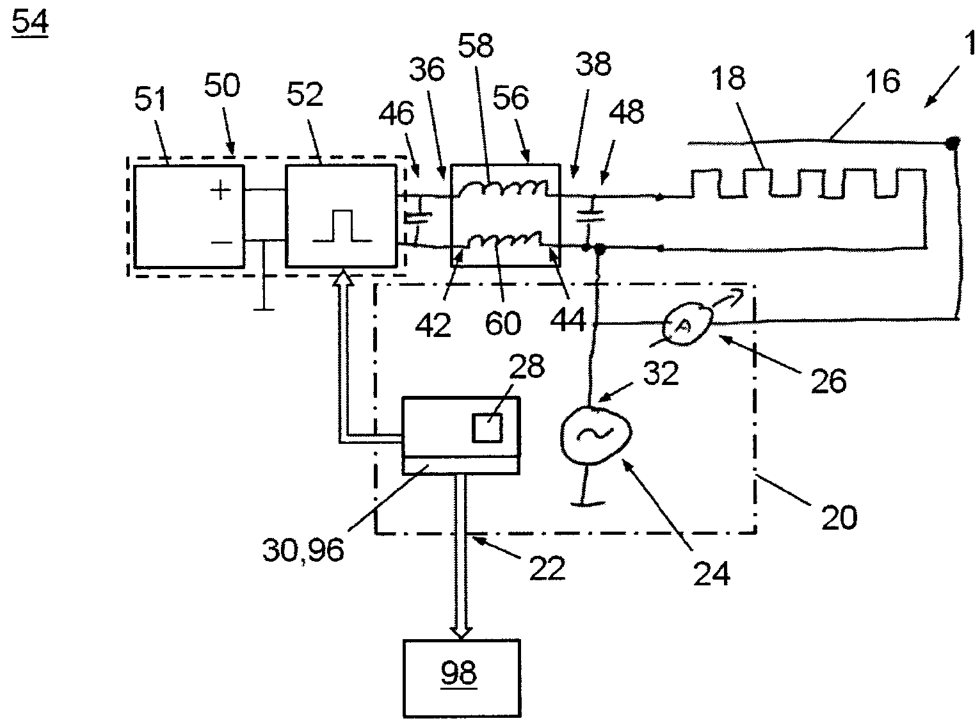
22
20
24
98

Fig. 2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56
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98

Fig. 3

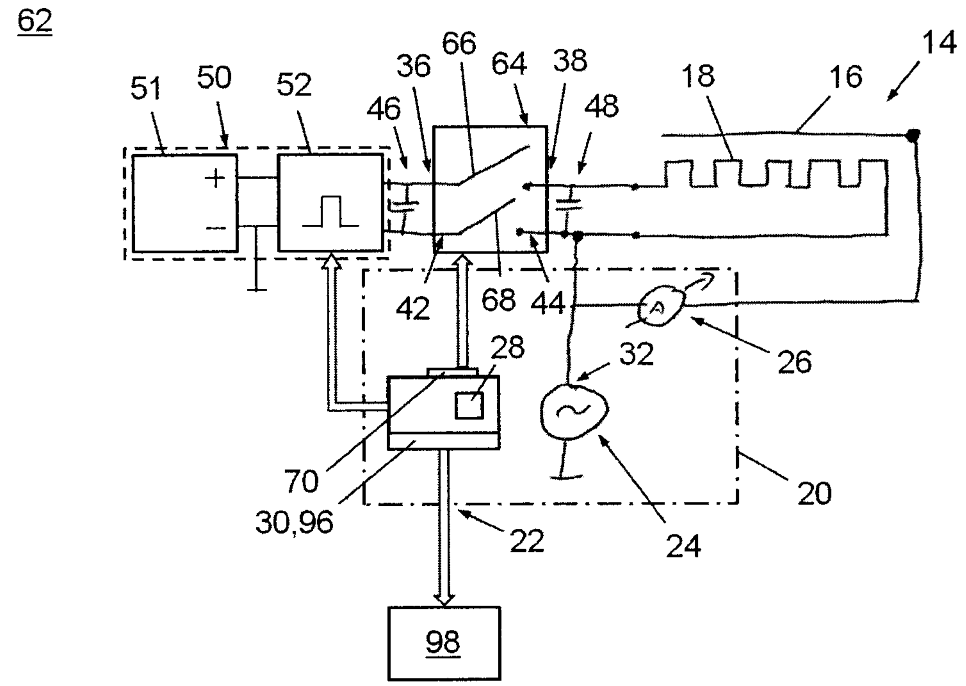
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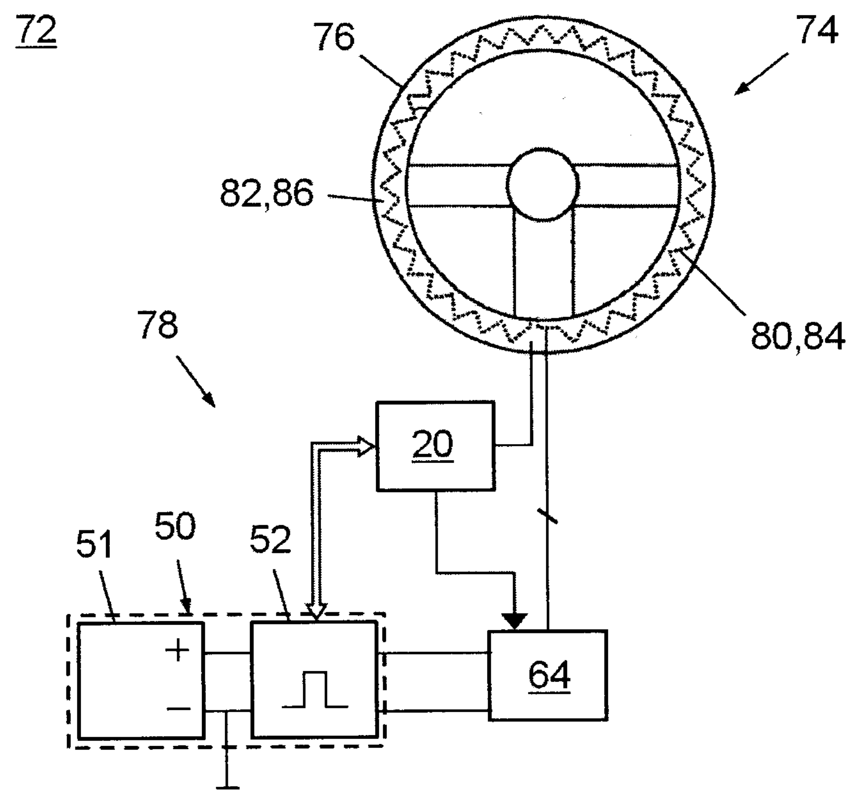
Fig. 4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64

Fig. 6

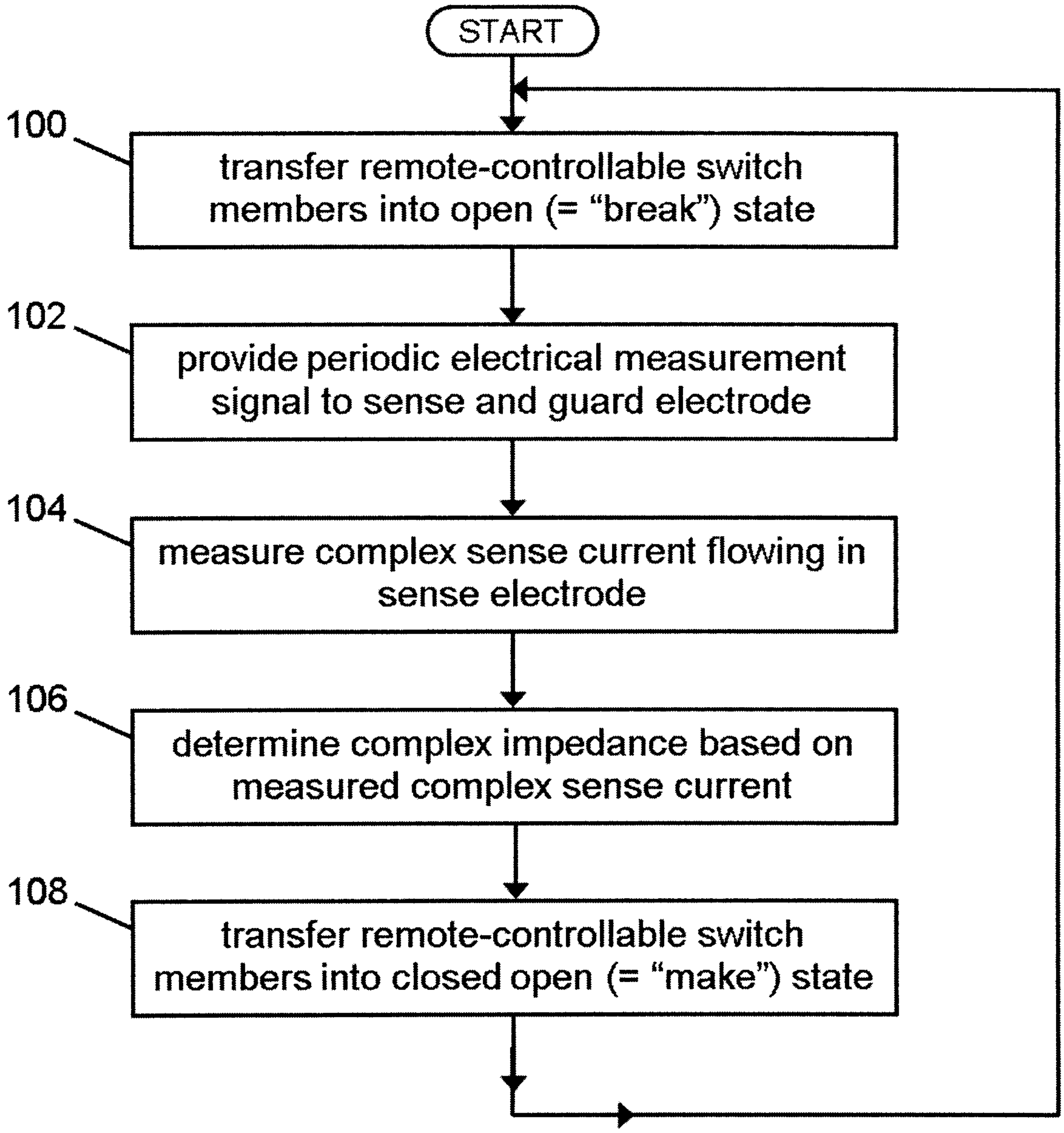
START
100
transfer remote-controllable switch members into open (= “break”) state
102
provide periodic electrical measurement signal to sense and guard electrode
104
measure complex sense current flowing in sense electrode
106
determine complex impedance based on measured complex sense current
108
transfer remote-controllable switch members into closed open (= “make”) state

Fig. 5