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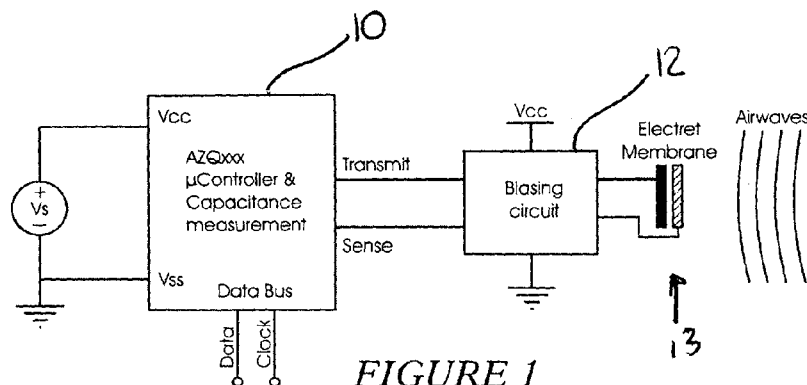


FIGURE 1

(57) Abstract: A low-cost motion detector based on capacitive sensing, which uses non-MEMS transducers, external to an integ-
rated circuit, to measure a capacitance change.

MULTIPLE MEDIA CAPACITIVE SENSOR

BACKGROUND OF THE INVENTION

[0001] The invention pertains to the use of a range of transducers in conjunction with, and external to, a capacitive sensing IC (integrated circuit) to sense motion in multiple media by measuring capacitance variance.

[0002] Capacitive motion sensing using MEMS devices is a well-researched and commercially developed field. A fair amount of integrated circuits exist that can measure motion in one to three dimensions. However, the cost of the devices still prohibits deployment in applications that are highly cost sensitive. Furthermore, the capacitive transducer of a MEMS device, being contained within the confines of an integrated circuit housing and typically etched into a semiconductor substrate, is fixed in dimensions and composition. Adjustment of transducer characteristics to suit a specific application is not feasible. If a change in capacitance due to motion for a particular MEMS device is not sufficient in a certain application, the selection of a new integrated circuit is required.

[0003] In the transport industry, low cost vial and liquid based shock sensors are still employed to measure shock above a certain threshold. If a consignment of fruit is received after intercontinental shipment, the activation of this type of sensor is an indication that the fruit has experienced too large a shock. This results in the consignment being scrapped. However, due to the nature of the sensors, a time stamp of the shock is not available, thus making the apportioning of the cost, or identifying the probable cause, difficult.

[0004] Presently motion, acceleration and tilt sensors are used in a number of high end portable electronic products, specifically smart phones. Typically, these would be

used to wake a unit from a deep sleep mode as soon as the unit is moved, to orient the unit's display according the manner in which it is held, and to record motion and shock, either for protection or gaming purposes. However, lower end portable electronics of the present state of the art seldom utilize any motion sensors, as the cost and power consumption thereof prohibit it.

[0005] A demand to detect motion in a cost effective and non-intrusive manner in kitchenware, white goods and similar consumer products also exists. For instance, water jug filters need replacement on a regular basis. However, to alert a user continually in a visible or auditory manner when a filter has exceeded its useful life is not feasible from a battery cost, size and environmental impact point of view. To use a MEMS based motion sensor to detect motion of the jug as it is picked up, and placed down, and only then to alert the user in a visible or auditory manner, is prohibited by the cost of this type of device.

[0006] In the manufacture and transportation of high-end electronic products, such as displays and televisions, the ability to monitor impact on the products can alleviate damage and costly repairs and returns. In conjunction, most displays and televisions of the present state of the art, and future, use or may use capacitive sensing technology to discern touches from a user for control purposes. If a MEMS based acceleration or motion sensor IC is used to detect impact, not only will cost increase, but the possibility to utilize the same IC for touch and impact detection would be negated.

[0007] To detect motion of air due to audible sound waves, and obtain correlating data in digital format, the present state of the art dictates that an analog signal from a transducer such as a microphone must first be amplified and filtered, and must then be converted via an A/D circuit. This would typically imply that an application which

needs to utilize sound and touch as activation inputs may require at least two IC's, which might increase cost beyond feasible limits. Ideally, a single IC that can detect both sound and touch would enable such applications.

[0008] To detect human heart rate, two main methods are used in the present state of the art. Firstly, electrodes which make galvanic contact with a user's skin conduct an electrical signal present on the skin to an amplification circuit. Alternatively, an infrared LED and sensor are used to detect a light permeability change due to blood being pumped rhythmically by the heart. This change in infrared light permeability is typically measured on the tip of a finger, or on an earlobe. However, the infrared technique requires the subject to stay fairly immobile and, as such, it is not generally practical for sport applications. The use of galvanic electrodes on adjustable straps around a user's chest to measure heart rate and to transmit a measurement to a wrist-worn display is well known, and a fairly mature industry. However, the electrodes need to stay fairly dry to ensure proper signal pickup, which implies a waterproofing requirement with a heart rate monitor. If the movement in skin due to heart rate at pressure points such as the wrist or fingers can be measured without galvanic contact, via an insulating dielectric layer, at low cost, a number of the aforementioned drawbacks can be overcome.

[0009] From all the above, it is clear that a need exists for a low cost motion sensor which utilizes a capacitive sensing IC in conjunction with a number of transducers external to the IC. The invention disclosed hereafter purports to address this need.

SUMMARY OF THE INVENTION

[0010] The disclosed invention constitutes a low-cost motion detector based on capacitive sensing. Its main characteristic is the fact that all the capacitive

transducers utilized are non-MEMS and external to an integrated circuit which measures the change in capacitance. In the preceding and following disclosure, "transducer" includes a complete assembly used to convert a motion into a capacitance change, and comprises electrodes, dielectric material, interconnects and other structural elements. The aforementioned main characteristic makes it possible to detect motion in a cost-effective manner in three of the four material states i.e. in gasses, liquids and solid materials. It also enables the possible adjustment of transducer dimensions or composition to suit a specific application, without the need to change the integrated circuit.

[0011] In a first instance, it may be possible to detect sound, or the motion of air, quite reliably according to the present invention by using simple electret films as transducers. During the manufacture of electret films, charge is retained within the film. This is analogous to the retention of magnetic fields in permanent magnets through the orientation of magnetic domains. Moving such a film, metalized on one face, closer to or further from a conductive surface results in a change in capacitance, and, accordingly, in voltage. According to the present invention, a separate capacitive sensing IC may be used to measure this change in capacitance or voltage. If the motion of the electret film is due to sound waves, the digital output of the capacitive sensing IC should be proportional to the amplitude of the sound waves. In fact, it may be quite feasible to use the electret film contained within a JFET amplified electret microphone, which is of extremely low cost, to measure sound quite accurately with a mutual capacitance sensing IC.

[0012] Motion detection according to the present invention with an electret film as a transducer is not restricted to air alone. Given the typical thickness of an electret film available commercially, motion detection could be feasible in other gasses or in

liquids by placing the film within the medium, or with one surface of the electret film touching the medium, and thus exposed to motion and pressure changes. If motion in a solid material needs to be detected, the film could be attached along a periphery of the film to the solid material. Due to the difference in inertias of the film and of the solid material, motion changes should cause film deflection, which may be measured as a change in capacitance. As with the electret microphone implementation mentioned above, it may also be feasible to use a biasing and transistor circuit to amplify the voltage signal obtained due to motion of an electret film, contained in, or attached to, a liquid, gaseous or solid body, and measure this signal directly with a capacitive sensing IC. A number of filtering techniques may also be applied to the signal before using it to inject charge into the capacitive sensing IC. For instance, if a periodic signal such as human heart rate, or engine combustion cycle, needs to be measured, a filter with a relevant pass band centred on the expected periodic frequency may be employed. Or, if the intention is to measure shock impulses, for instance during fragile goods transport, a peak detector may be employed to capture the highest motional amplitude experienced.

[0013] It might further be possible to utilize the techniques of the present invention to detect human skin motion, specifically due to heart rate, in a cost-effective and adjustable manner. The amount of skin deflection on, for instance, the wrist, due to heart rate is very small. Without skin stretching, it is seldom perceivable to the naked eye. With recent advances in the resolution, relative to cost, of capacitive sensing IC's, it may now be possible to detect these small skin deflections using the principles of the present invention. By placing two inexpensive electrodes, separated by a thin layer of a compressible dielectric medium, against the skin, and keeping the electrode further from the skin fairly static relative to the skin directly beneath the electrode pair, a change in capacitance proportional to heart rate can be effected.

According to the present invention, this could potentially be measured with a capacitive sensing IC, and may be digitally filtered to give an accurate representation of heart rate. Further, the present invention allows the manner in which the electrodes are kept in place in the vicinity of the heart-rate based deflecting skin section to be quite varied. For instance, skin motion due to heart rate may be measured at a user's finger through the use of a ring-like device to keep the electrodes in place. Or the electrodes may be inserted underneath a wristband of an athlete's watch. The number of electrodes also do not have to be constrained to two, but multiple pairs may be used. For instance, according to the present invention, multiple pairs of electrodes may be incorporated into the material of a sports watch strap, thereby reducing the sensitivity to electrode position of the heart rate monitoring system. Also contained within the ambit of the present invention is a method of using a volume charged, void-filled electret material, such as that marketed under the name EMFIT, to measure human heart rate with a single capacitance sensing IC. If the capacitive heart rate transducers are incorporated into the structure of a sports watch, be it in the strap or the watch body, a self-contained unit is formed, without the need to transmit the heart rate data to the watch via an air interface, as is presently done with chest-strap based heart rate monitors.

[0014] Another embodiment of the present invention for the detection of human heart rate teaches the use of a semi-rigid strap to be placed securely around a user's wrist. Pliable, conductive material is situated between the user's wrist and the semi-rigid strap, separated from the strap by a compressible dielectric material, which may be air. The conductive material is electrically floating relative to the measurement circuitry which is employed, or it may be grounded. A number of electrodes are placed on the semi-rigid strap, in close proximity to the pliable conductive material which is situated against the user's skin. When the user's skin moves due to heart

rate, the pliable conductive material moves toward and away from the electrodes. This may be measured as a proportional change in capacitance between two specific electrodes (mutual), or between an electrode and earth (self-capacitance). By taking an aggregate of the capacitance change from all the electrodes situated on the semi-rigid strap, an accurate indication of a user's heart rate may be obtained without being overly dependent on the placement of the semi-rigid strap, or how tight it is pulled against the user's skin.

[0015] In yet another embodiment of the present invention, an electret microphone, with integral transistor amplification, as discussed above, is used in conjunction with a first air cavity and a flexible membrane to detect human heart rate. The first air cavity is covered by the flexible membrane, with the membrane placed on the user's skin, in an area where heart action typically results in skin motion. The first air cavity is sealed, except for a small channel or pipe, with a diameter substantially less than the dimensions of the first air cavity, leading from one wall or side of the cavity. The distant end of the channel or pipe opens to a second sealed cavity which contains the electret microphone. The electret microphone is positioned in such a manner that its electret membrane is maximally exposed to the channel or pipe, in terms of air or gas flow. When a user's skin moves the flexible membrane, due to the user's heart rate, the air or gas in the first cavity is compressed, and along with it the air or gas in the channel or pipe. This results in air or gas movement against the electret membrane of the microphone. Due to the significant smaller dimensions of the channel or pipe, the air or gas movement in the first cavity is amplified, resulting in increased movement of the electret membrane compared to what would be obtained if the microphone were to be placed directly into the first air cavity. This increase in movement typically results in a larger signal from an electret microphone and

capacitive sensing combination, as disclosed above. Therefore, it may be used to detect a heart rate with more fidelity than what would be obtained otherwise.

[0016] In the case of a ring-like device worn by a user on his/her finger, the possibility exists within the scope of the present invention to make the ring completely self-contained. An extremely low power wireless link may be used to transmit heart rate data from the ring to a wrist-worn, or at another location, display. Therefore, no encumbering wires will lead to the heart rate monitoring ring, with it drawing its power from a battery supply. Furthermore, according to the present invention, it is possible to place such a heart rate monitoring ring on not only one hand, but on both hands, of the user. This might increase the heart rate signal's accuracy and fidelity. Any signal not common to both rings may be seen as noise, and ignored. Typically these not-common signals will result from movement of the user's arms or body, which may also cause an amount of skin deflection.

[0017] Measurement of heart rate according to the present invention, as described above, may be implemented in a completely waterproof manner. As the electrodes do not have to be in galvanic contact with the user's skin, but only mechanically connected to it, waterproofing may be realized in a cost effective manner. The waterproof nature could potentially pose a significant advantage in many sports applications, especially if combined with the inherent cost-effectiveness of the present invention.

[0018] In the above disclosed embodiments concerning measurement of heart rate, and any other heart rate measurement embodiments that fall within the scope and spirit of the present invention, one or more transducers may be placed around any limb or the user, or any other body part, as required.

[0019] Tilting motion of devices may also be accurately measured according to the present invention. By using a capacitance sensing IC in conjunction with a number of transducer components, such as springs, flexible membranes, rolling balls or contained liquid bodies, it may be possible to measure tilt. For instance, by attaching
5 an electrode to a spring which is anchored to the body being tilted, a change in either mutual or self-capacitance may be measured which should be proportional to tilt. By using a plurality of springs, tilting motion may be measured in 2 dimensions. If track is kept of tilting progression, it might further be possible to determine not only tilt, but also which side is up. If tilting motion along a specific axis only needs to be
10 measured, it may be possible to use flexible membranes, such as a flexible printed circuit, or FPC, in the above manner. Flexible membranes tend to be fairly stiff in movement parallel to their surface area, and only bend perpendicular to it, making them ideal for constrained tilting measurement.

[0020] Another embodiment of the present invention would be to use a rolling ball to
15 detect tilting motion. Such an arrangement may be used in various ways with a capacitive sensing IC to measure tilt. For instance, if a metal ball is rolled by tilting motion along a predetermined, constrained track, with electrodes placed in a chosen location alongside the track, a measureable change in capacitance might be realized. As the metal ball rolls closer to or further from the electrodes, it should perturb the
20 electrical coupling between the electrodes. In a mutual capacitance arrangement, one electrode may be a transmit electrode, and another electrode may be a sense electrode. As the ball rolls closer to the electrodes, less charge should be transferred between the transmit and sense electrodes, which should result in a decrease in measured capacitance. Conversely, by grounding one electrode and measuring the
25 self-capacitance of the other, an increase/decrease in capacitance is measured as the ball rolls closer/further due to tilting of a hosting device.

[0021] One drawback of using a metal ball to measure tilt is the possibility for a clicking sound as the ball collides with barriers at the end of the constrained track. Further, the output is typically a binary signal, as the ball would normally not move until a certain tilt angle is exceeded, upon which it would roll right to an opposed end of the constrained track. Therefore tilt angle may be difficult to measure, with only the occurrence of a tilting action easily detected. These constraints may be overcome by introducing a curvature to the rolling track of the ball. In the extreme, a spherical vessel may be used to contain the rolling ball, with a plurality of electrodes which may be placed around a periphery of the sphere. In this manner, a more exact value of the tilt angle should be discernible, and clicking sounds due to host tilting should not be evident. However, if the sphere is shaken or vibrated, clicking sounds might still be heard. Further, due to the solid nature of the ball and the requirement that it rolls fairly freely, with sufficient spacing to a minimum number of electrodes inside the sphere, its maximum diameter is limited, and it will typically not easily give an exact angle of tilt.

[0022] According to the present invention, the use of a ionic, liquid body instead of a rolling ball allows a more exact measurement of the tilting angle of the hosting device. The movement of the liquid body to and from electrodes should be much more continuous, and the liquid should mate perfectly with boundaries of the vessel containing the liquid, ensuring the biggest effect on electric fields emanating from the electrodes. Further, it should ensure a silent, cost effective tilt sensor without any clicking sounds. Naturally, the fluid (liquid) used needs to contain enough ions to disrupt the nominal electric field lines between electrodes. And for applications in the region of, or below zero degrees Celsius, the fluid type will have to be carefully chosen to ensure it does not freeze, or lose its viscosity in a substantial manner.

[0023] It is evident that the signals from capacitive tilting motion sensors as described above should be static or quasi-static in nature, and should need little filtering if the hosting device is tilted only. However, normal use may typically include motion which is acceleratory or vibratory in nature. To discern tilt from these, a filter producing the envelope of the measured capacitance related signal might be required. Should the capacitance be stable at a certain new value for a minimum period, a tilt can be annunciated. On the other hand, as pointed out in the background, a need also exists for low-cost motion, non-MEMS sensors which can measure acceleration or vibration. The above mentioned embodiments of the present invention that utilize springs or flexible membranes as part of the required capacitive transducers may be used to measure such motion. In the case of acceleratory motion, an output signal from a capacitive sensing IC should typically be decaying and oscillatory. Therefore, if the signal is filtered correctly to determine its primary peak value, the period at which this peak is maintained, and its decay period, a fair amount of information about the acceleratory motion can be garnered. In a similar manner, vibratory motion should produce a static or quasi-static envelope signal which, if filtered correctly, may be used to identify vibration, using a spring or flexible spring-based transducer and a separate capacitive sensing IC.

[0024] In broad terms therefore, the invention provides a module comprising a capacitive measurement integrated circuit coupled with at least one capacitance transducer for use in a product, wherein said at least one transducer is located external to the integrated circuit, with said integrated circuit controlling and performing a charge transfer capacitance measurement process, said module characterized by at least one transducer designed to be positioned on or around limbs or body parts to facilitate the measurement of a heart rate.

[0025] The product may be a heart rate monitor wherein the transducer detects motion due to a variation in blood pressure during a heartbeat cycle.

[0026] The transducer may make use of a compressible dielectric material, said dielectric material separating a plurality of electrodes used for capacitive sensing, and wherein at least one of the electrodes is fairly static relative to the movement of a user's skin, or of a volume charged, void-filled, electret material, said electret material being compressible, and placed against a user's skin, with skin motion causing capacitance changes according to the material properties of said electret material.

[0027] At least one layer of conductive material may be positioned on an outside of the transducer construction in order to help shield electrodes of the transducer from causes of noise.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] The invention is further described by way of examples with reference to the accompanying drawings in which:

Figure 1 shows an exemplary embodiment of the present invention which detects motion in air, typically due, but not limited to, audible sound, through the use of inexpensive electret film technology;

Figure 2 shows an exemplary embodiment of the present invention which can detect motion of human skin, typically caused by but not limited to, a pulse or heart rate;

Figure 3 shows an exemplary embodiment of the present invention which can detect tilting motion of a device;

Figure 4 shows an exemplary embodiment of the present invention which can detect, but not limited to, vibratory or accelerative motion of a device in one or two dimensions;

Figure 5 illustrates an exemplary implementation of a tilt/vibration/movement transducer according to the present invention, that utilizes, but which is not limited to, a mm scale spring attached to an electrode;

Figure 6 illustrates an exemplary implementation of a 2.5D motion transducer according to the present invention, that utilizes, but which is not limited to, a ring of 4 electrodes surrounding a mm scale spring attached to an electrode;

Figure 7 illustrates an exemplary implementation of a transducer for skin motion, according to the present invention, that utilizes, but which is not limited to, two rigid electrodes separated by a compressible medium;

Figure 8 illustrates an exemplary implementation of a transducer that can detect either tilting, vibratory or accelerative motion according to the present invention, utilizing, but not limited to, a rolling ball, constrained to a predetermined track and space, which perturbs electric fields surrounding a set of electrodes;

Figure 9 illustrates an exemplary implementation of a transducer that can detect tilting, vibratory or accelerative motion by containing an electric field disrupting object, typically a metal ball or a small amount of liquid, within a volume, typically a sphere or cylinder, with electrodes on a periphery of the volume to measure corresponding changes in capacitance;

Figure 10 illustrates an exemplary implementation of a motion transducer according to the present invention, which utilizes, but which is not limited to, a low cost flexible printed circuit (FPC) material to realize deflecting beam and capacitive sensing electrodes;

Figure 11(A) illustrates details of an exemplary biasing circuit for the sound sensor of FIG. 1;

Figure 11(B) illustrates an exemplary embodiment of the present invention to detect motion in liquids, gasses or solid bodies through the use of an electret film and a biasing and amplification circuit used to inject charge directly into a capacitive sensing IC;

Figure 11(C) illustrates an exemplary embodiment of the present invention similar to that of Figure 11(B), but with the addition of a peak detector to capture a signal corresponding to the maximum motion experienced by an electret film transducer;

Figure 12 illustrates an exemplary embodiment of a capacitive heart rate sensor attached to an inner surface of a watch wristband;

Figure 13 illustrates yet another exemplary embodiment of a capacitive heart rate sensor that employs deformable cells within the wristband of a watch, with electrodes contained within each cell to measure corresponding changes in capacitance;

Figure 14 illustrates an exemplary embodiment of a capacitive heart rate transducer in the form of an adjustable ring, to be placed around a user's finger; and

Figure 15 illustrates an exemplary embodiment that utilizes a semi-rigid strap around a user's wrist, in conjunction with pliable conductive material, and a plurality of electrodes to detect human heart rate.

DESCRIPTION OF PREFERRED EMBODIMENTS

[0029] The following description of various embodiments, according to the preceding graphical illustrations, is given in an effort to fully disclose the invention, to enable sufficient comprehension by persons skilled in the art of capacitive sensing and motion detection. However, the scope of the disclosed invention should by no means

be limited by said description, and it is possible that a range of other embodiments can be realized that still fall within the claims to be presented hereafter.

[0030] The combination of electret film and capacitive sensing technology offers the possibility to realize motion detection in three of the four material states that is in gaseous substances, liquids and in solid materials. When the electret film moves relative to a fixed electrode, a change in capacitance occurs. Given the fixed charge of the film, the change in capacitance is accompanied by a voltage change. As illustrated in exemplary manner in Figure 1, a capacitive sensing IC 10 may be used to detect the change in capacitance due to film motion directly, or the voltage change V_s may be measured by the same IC, using a simplistic biasing circuit 12. In the exemplary embodiment of Figure 1, sound may be detected accurately through a combination of an electret film and a capacitive sensing IC. Propagating air waves carry the sound, and also deflect the electret film inwards and outwards, resulting in a changing voltage / capacitance, which could be measured by the capacitive sensing IC. Another embodiment would be to use an extremely low cost electret microphone 13 as a transducer. These microphones are very commonplace, and are used in a wide range of consumer electronic products, such as mobile telephones, headsets for personal computer use, fixed telephones etc.

[0031] A biasing circuit 14 may be utilized, as depicted in exemplary manner in Figure 11(A), to bias a JFET 16 typically contained within this type of low cost electret microphone. Once biased correctly, the voltage from the JFET may be used to drive a sensing pin 18 of a capacitive sensing IC, as depicted in Figure 11(A), with the driving current typically proportional to the amplitude of the sound waves incident on the microphone. A transmit pin 20 of the capacitive sensing IC is typically utilized to energize the final stage of the biasing circuit depicted in Figure 11(A), and to

charge a fixed capacitance C2 between the transmit and sense pins, resulting in a more stable signal. This final stage biasing method should reduce current consumption significantly, since energy is only dissipated when the transmit pin is driven high.

5 **[0032]** Figure 11(B) presents another exemplary embodiment to detect motion using an electret film as a transducer 24 in conjunction with an FET, or an alternative switching element, -based amplification 26, and a biasing circuit 28 to inject charge directly into a capacitive sensing IC 30. The capacitance between electrodes 32 and 34 should be directly proportional to the charge contained within an electret film 36 and the spacing 38 between the film 36 and the electrode 34. If either the film or the
10 opposite electrode moves closer to or further from the other electrode, due to motion of the hosting liquid, gas or solid material, the capacitance should increase or decrease respectively. Typical values which may be practically realized are in the order of 30pF for the spacing 38 at its maximum, and 15pF for the spacing at its
15 minimum. Since the charge of the electret film is typically fixed and swamps the charge stored due to the air dielectric, the change in capacitance should also imply a proportional change in voltage across the electrodes 32 and 34. This voltage may be applied to a terminal 42 of the FET amplification circuit 26. The output of the amplification circuit may be used as an input to the biasing circuit 28, at a terminal
20 44. Once biased and amplified correctly, the voltage signal due to the motion of the liquid, gaseous or solid material body hosting the electret film may be used to inject charge directly into the capacitive sensing IC 30, resulting in a digital signal which is directly proportional to host motion. A diode 46 typically serves dual functions. It provides a path for charge flow from the electrode 34 to the electret film 36, to restore charge equilibrium once the spacing 38 has been decreased. Secondly, it protects the control terminal of the switching element 26 from negative voltage

spikes, once the electret film or opposite electrode moves further away from each other.

[0033] Various filtering circuits may be applied to the embodiment in Figure 11(B) to detect certain categories of motion. For instance, in Figure 11(C), the output of an amplification and biasing circuit 50, at a terminal 52, is applied to a peak detection circuit 54, before being used to inject charge into a capacitive sensing IC 56. In this manner, it may be possible to record the maximum motion of a particular hosting body, be it fluid, gas or solid material. In other words, such a peak detection circuit-based embodiment may be used to detect shock of a device in a cost-effective, flexible and reliable manner. It should be understood that a large number of filtering circuits may be used in the place of the peak detection circuit 54, and still fall within the scope of the invention. For instance, a band pass filter circuit may be used, with a pass band from 0.4HZ to 5Hz, to detect human heart rate due to motion of the skin.

[0034] As illustrated in exemplary manner by Figure 2, the same capacitive sensing IC may be used in conjunction with a transducer 60, of the kind shown in Figure 7, to accurately detect skin motion caused by a pulse / heart rate. By placing an electrode 62 against the skin 64 of the body, and a easily compressible medium 66 between the electrode 62 and an electrode 68, which is fitted to a base 70 which is fairly static in position relative to the skin 64, the deflection of the skin 64 due to pulse rate may be measured accurately using a mutual capacitance sensing IC 56. The embodiment in Figure 7, with the electrode 68 connected to a transmit or energizing pin 74 of the IC 56, and with the electrode 62 connected to a sensing pin 76, is purely exemplary, with a large number of other embodiments possible that will fall within the scope of the presently disclosed invention.

[0035] For instance, as depicted in an exemplary manner in Figure 12, it may be feasible to incorporate one or a plurality of capacitive heart rate transducers 80 into a wrist band 82 of a watch 84, which displays the wearer's heart rate. By using digital signal processing, the deflection of skin under the wrist band due to the wearer's pulse may be discerned from deflection due to body motion.

[0036] Another embodiment, depicted in Figure 13, utilizes a plurality of sensor cells 86, incorporated directly into the material of a wristband 88 of a watch 90. The cells are separated by walls, with each cell constituting a self-contained skin deflection device, and therefore heart-rate, monitoring unit. Figure 13(A) shows, on an enlarged scale, a cell 86 which contains two electrodes 92 and 94, separated by a compressible dielectric medium 96, which may or may not be of similar material as the cell material 98, which contains the whole assembly. It also falls within the scope of the present invention, to use a compressible liquid or gel for the dielectric medium 96 or cell material 98. As above, the electrodes 92 and 94 may form part of a mutual capacitance sensing circuit. As the skin expands due to a heart rate variation, it should push the electrode 94 closer to the electrode 92, resulting in a capacitance increase, which could be measured by a capacitive sensing IC contained within the watch 90. As stated before, through the use of multiple cells within the wristband of the watch, the challenge of placing the heart rate transducer on an exact area of skin to obtain a highest signal to noise ratio may be overcome. Capacitance measurements from multiple cells may be compared with an expected waveform to determine which cell is most optimally placed, and then use the information from that cell to determine the heart rate. Alternatively, the information from all the cells could be continually gathered and processed, to improve the fidelity of the heart rate monitoring system.

[0037] In another example, depicted in exemplary manner in Figure 14, an adjustable ring 102, containing one or a plurality of capacitive heart rate sensors 104 according to the invention are placed on a person's finger. A user may adjust the ring with swing arms 106 and Velcro™ straps 108, thus compressing the skin, until his/her pulse is sensed reliably. As noted previously, a body of the ring 102 may contain a battery supply and an extremely low power wireless link, making the ring completely self-contained and free of encumbering wires.

[0038] Figure 15 depicts yet another exemplary embodiment of the present invention. A semi-rigid strap 110 is placed around a user's wrist, and secured and tightened by straps 112 and 114. For example, these straps may be formed from Velcro™. On an inner side of the strap 110, a pliable conductive strip 116 is used. This conductive strip is therefore placed against the user's skin. A plurality of electrodes 118 is located on an inner face of the semi-rigid strap 110. These electrodes may be used for self-capacitance or mutual-capacitance measurements, used to determine the user's heart rate. A thin layer of compressible dielectric material 122 separates the pliable conductive material 116 and the semi-rigid strap 110. The pliable conductive material 116 floats electrically relative to the capacitive measurement circuit, or it may be grounded. As the user's skin moves due to his or her heart rate variation, the pliable conductive material 116 is moved closer to or further from the electrodes 118, resulting in a change in the measured capacitance, be that self- or mutual capacitance. By taking an aggregate of the measurements from all the electrodes located 118 on the semi-rigid strap 110, the present invention teaches that it may be possible to obtain an accurate indication of the user's heart rate without the measurement being overly dependent on the exact placement and location of the whole assembly on the user's wrist.

[0039] Figures 3 and 4 illustrate in exemplary manner that the capacitive sensing IC 56 may also be used to detect tilting, accelerative or vibratory motion in a solid medium, such as spring steel or a flexible printed circuit board (FPC), using the correct transducers. A large number of transducers of the above mentioned type may be utilized that will fall within the scope of the present invention. For instance, in Figure 5, a transducer 130 is shown that may be used to detect vibratory, accelerative or tilting motion in one or two dimensions. An electrode 132 is attached to a flexible medium 134, which may be a small spring. The combination of the flexible medium and the electrode is anchored at a location 136, which will typically be the hosting device. Electrodes 138 and 140 will typically be below the electrode 132, but not touching it. As the host device is vibrated, tilted or accelerated, the electrode 132 should swing from a centre point between the electrodes 138 and 140. The electrode 132 should either move closer to the electrode 138 or 140, or move closer to or further from both, depending on the direction of the motion. The movement may be detected through mutual or self-capacitance sensing. By making the electrode 132 a transmit or energizing electrode, and the electrodes 138 and 140, sensing electrodes of separate channels, mutual capacitance may be used to detect the motion. Conversely, by tying the electrode 132 to ground, and sensing the self-capacitance of the electrodes 138 and 140 respectively, motion may also be detected.

[0040] Figure 6 presents another exemplary embodiment of a 2.5D movement sensor 144, according to the present invention. As before, an electrode 146 is attached via a flexible beam or spring 148 to a point 150 which is anchored to a host device. The electrode 146 is surrounded by a ring of four electrodes 152, 154, 156 and 158. Vibratory or accelerative motion may be detected in two dimensions. Tilting motion may be detected in two dimensions, being the x and y directions, and it may

also be possible to monitor which side is upwards. This should be possible because the earth's gravitational force is always directed downwards, and it is not possible to obtain an upturned device without progressing through a maximum amount of tilting in a particular direction. As with the transducer in Figure 5, either mutual or self-capacitance sensing may be used to detect the motion of the above electrodes, and thereby, of the hosting device.

[0041] Figure 8 illustrates yet another exemplary embodiment of a tilt or motion sensor according to the present invention. In Figure 8(A) a ball 160, typically but not necessarily from metal, with a diameter typically on the mm scale, rolls along a pre-determined and constrained track 162. Two electrodes 164 are situated at one end of the track 162. The ball may or may not make galvanic contact with the electrodes. As the hosting device is moved along an axis parallel to the ball track 162, the ball should roll closer to or further from the electrodes 164. One possibility, according to the present invention, is to make the electrodes 164 the transmit (164A) and sense (164B) electrodes of a mutual capacitance circuit. As the ball rolls closer to or further from the electrodes, the mutual capacitance should decrease/increase accordingly, which may be measured by the IC 56 depicted in Figures 3 and 4. However, embodiments of the present invention using a rolling ball need not be constrained to a mutual capacitance implementation. By using only one electrode at one end of the constrained rolling track for the ball, a change in self-capacitance can be effected through host device motion or tilting, which can be measured.

[0042] To ensure that the rolling ball 160 in Figure 8 does not get stuck, and always starts from a known position, an incline 170, relative to the gravitational force of the earth, may be inserted in the constrained rolling track 162 (see Figure 8(B)). Further, to avoid the clicking sound typically experienced with rolling ball motion sensors, a

curvature may be introduced into a track 172 (see Figure 8(C)). In this case, the ball will always start from the lowest point of the track, and if designed correctly, will not collide with a high impact during envisaged motion of the hosting device. Another variation of the embodiment presented in Figure 8 is to use a pendulum-like transducer, which swings metal closer or further from an electrode or plurality of electrodes.

[0043] If the curved rolling track is taken to the extreme, a spherical containment vessel of the ball, as depicted in an exemplary manner in Figure 9, will result. A sphere 174 contains a typically, but not necessarily, metallic ball 176, which can roll freely within it. Normally, the sphere would consist of insulating material. A plurality of electrodes are placed on the periphery of the sphere. In the example of Figure 9, four electrodes 178, 180, 182, 184 are placed on the periphery, typically isolated by the sphere material from contact with the ball 176. As depicted in Figure 9, the ball should always ultimately reside at the point in the sphere which is closest to the earth, due to the earth's gravitational force. If the electrodes 178 and 184 form a transmit and sense pair of a mutual capacitance circuit, and are connected to an external capacitive sensing IC, as per the invention, it is clear from the example of Figure 9 that tilting the sphere towards the electrode 180 should result in an increased measured mutual capacitance for the electrode pair 178 and 184. Conversely, one or more of the plurality of electrodes on the periphery of the sphere may be tied to ground, and the self-capacitance of the remaining electrodes may be utilized to monitor tilt. In the above manners, tilting of a hosting device may be measured with the transducer of Figure 9, with a large number of electrode combinations and uses possible.

[0044] As noted previously, a spherical transducer, as depicted in Figure 9, might still experience clicking sounds if the hosting device is shaken or vibrated. Due to the discrete nature of the rolling ball, it might also be difficult to obtain exact tilting angles. To overcome these drawbacks, an embodiment of the invention such as presented in Figure 9(A) may be used. An ionic fluid body 190 is used in the above mentioned sphere, instead of the rolling ball 176. As is evident, the perturbation of the electric fields between electrode pairs should be much more gradual. This may allow for a more exact determination of the tilting angle. It should result in a silent tilt sensor according to the present invention.

[0045] Figure 10 presents an exemplary tilting or motion transducer according to the present invention that utilizes a purely flexible printed circuit material implementation. A deflecting beam 190 is punched or cut into flexible material 192, with two electrodes 194 and 196 printed with a normal flexible printed circuit deposition process. The electrode 196 is placed on a T-piece that terminates the deflecting beam, and the electrode 194 is placed in a parallel position on the material 192, which is fairly static in position relative to the hosting device. If the hosting device accelerates, vibrates or tilts along an axis perpendicular to the surface of the material 192, the beam will bend, causing the electrode 196 to move further from the electrode 194. If electrodes are respectively connected to the transmit and sensing pins of a mutual capacitance sensing IC, the resulting reduction in mutual capacitance due to the motion can be measured accurately. Conversely, a self-capacitance sensing IC can also be used to detect motion according to the exemplary embodiment of Figure 10, by connecting one electrode to ground, and sensing the change in self-capacitance of the other.

[0046] As illustrated in Figure 10(C), another typical embodiment might use rigid PCB material 200 to implement a motion/tilting sensor in a manner similar to the above. A flexible printed circuit beam and T-piece similar to the above are used, but are soldered onto the rigid PCB at a location 202, and lifted by a support 204 to ensure that motion in two directions can be detected.

CLAIMS

1. A module comprising a capacitive measurement integrated circuit coupled with at least one capacitance transducer for use in a product, wherein said at least one transducer is located external to the integrated circuit, with said integrated circuit controlling and performing a charge transfer capacitance measurement process, said module characterized by at least one transducer designed to be positioned on or around limbs or body parts to facilitate the measurement of a heart rate.
2. The module of claim 1, wherein the product is a heart rate monitor, and wherein the transducer detects motion due to a variation in blood pressure during a heartbeat cycle.
3. The module of claim 2, wherein the capacitance measurement process detects changes in either self-capacitance, or in mutual capacitance, and wherein digital signal processing is used to increase signal to noise ratio and to isolate the heart rate.
4. The module of claim 3, wherein the transducer makes use of a compressible dielectric material, said dielectric material separating a plurality of electrodes used for capacitive sensing, and where at least one of the electrodes is fairly static relative to the movement of a user's skin.
5. The module of claim 3, wherein the transducer makes use of volume charged, void-filled, electret material, said electret material being compressible, and placed against a user's skin, with skin motion causing

capacitance changes according to the material properties of said electret material.

6. The module of claim 3, wherein the transducer comprises at least one layer of conductive material that is positioned on an outside of the transducer construction in order to help shield electrodes of the transducer from causes of noise.

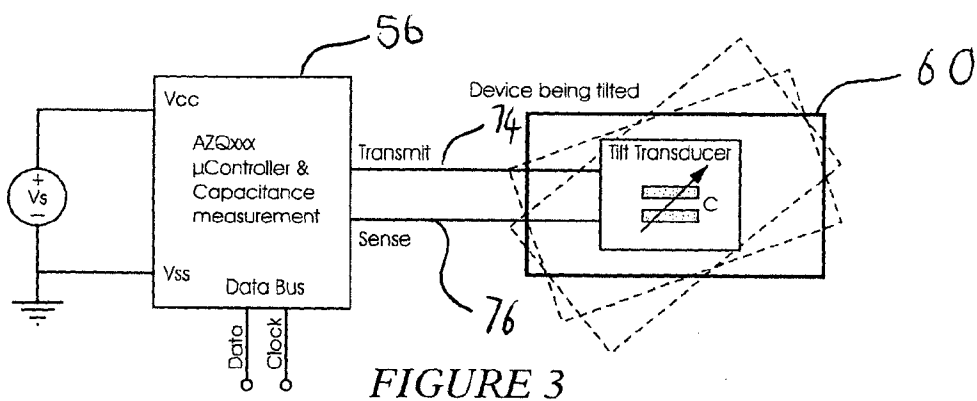
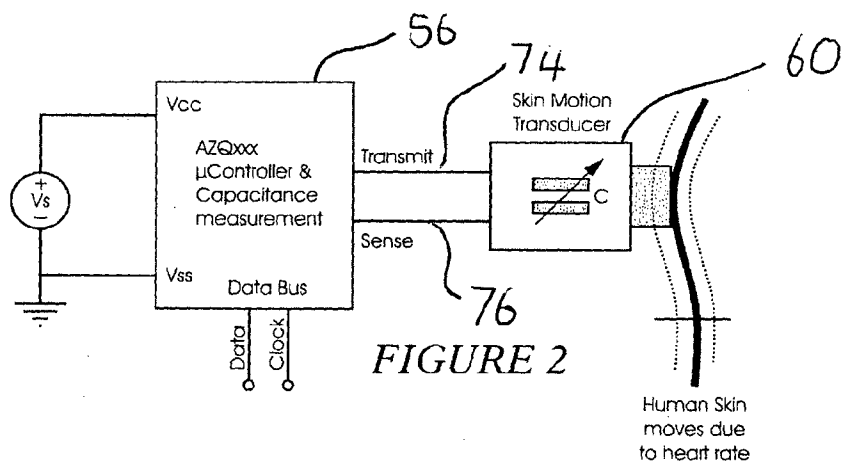
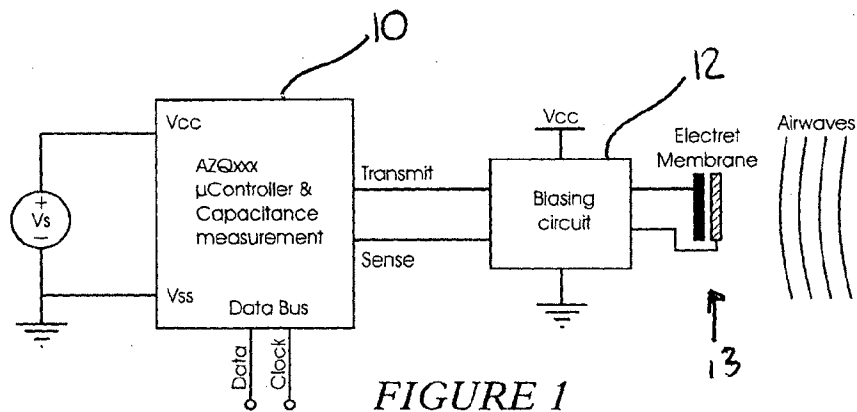
7. The module of claim 6, wherein at least one conductive material layer is connected to electrical ground.

8. The module of claim 3, wherein the transducer makes use of an electret based microphone, a first air or gas cavity, a second sealed air or gas cavity, a flexible membrane covering said first cavity, a pipe or channel with dimensions substantially less than that of said first cavity, said pipe or channel connecting said first and second cavities, wherein said microphone is optimally placed within said second cavity so as to be exposed to air or gas flow out of said pipe or channel, said air or gas flow caused by movement of a user's skin which presses against said flexible membrane.

9. The module of claim 3, wherein the transducer makes use of pliable conductive material situated between a user's skin and a plurality of electrodes which are used for capacitive sensing, and wherein a thin layer of isolating, compressible material keeps said electrodes and pliable conductive material apart, with said pliable conductive material either floating electrically, or being grounded to system ground.

10. The module of any one of claims 4 to 9, wherein the product also comprises a wristwatch, with the at least one transducer contained within a strap of said wristwatch, and being electrically or capacitively coupled to the wristwatch, or to capacitive sensing circuitry, if located externally to said wristwatch.
- 5 11. The module of any one of claims 4 to 9, wherein the product also comprises a ring-like device, to be worn by a user on his/her finger, with the at least one transducer contained by said ring.
12. The module of claim 11, wherein the ring is a self-contained unit, with its own power supply, and wherein it communicates sensed data via a wireless
10 connection to a main hosting unit such as a wristwatch, said hosting unit logging and displaying heart rate information for the user.
13. The module of claim 10, wherein the strap of the wristwatch contains multiple cells, said cells being physical or virtual entities, but in both cases identifiable by at least one electrode per cell, each cell producing a signal and wherein a
15 resultant heart rate signal is either obtained from an aggregate of the signals from the cells, or from the cell with the best signal.
14. The module of claim 1, wherein the product comprises sound detection circuitry, and wherein the transducer detects motion is in a gas or fluid.
15. The module of claim 8 wherein amplification and biasing circuitry is used and
) connected between a film of said electret and capacitive sensing circuitry.

16. The module of claim 15, wherein changes in mutual capacitance are measured, and wherein the biasing circuitry is driven from a transmit pin of the capacitive sensing circuitry, to decrease power consumption of a sensor.
17. The module of claim 14, wherein use is made of an electret film based microphone, with a JFET integrated into a housing of said microphone, as the transducer.
18. A low-cost motion detector based on capacitive sensing, which uses non-MEMS transducers, external to an integrated circuit, to measure a capacitance change.



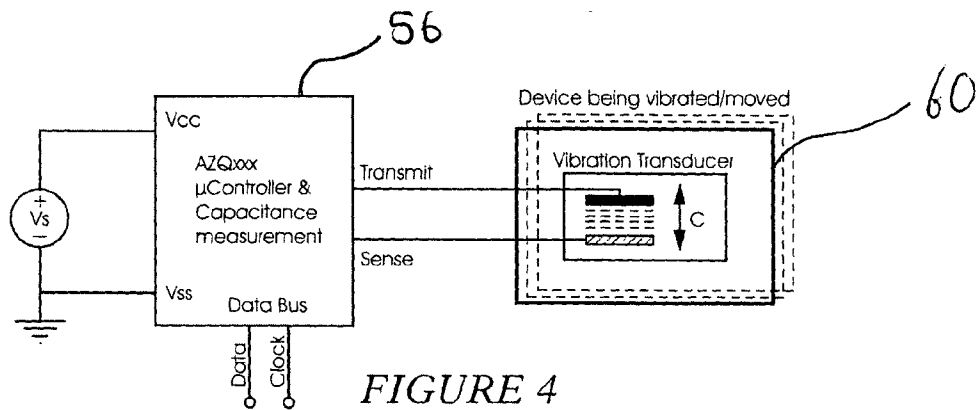


FIGURE 4

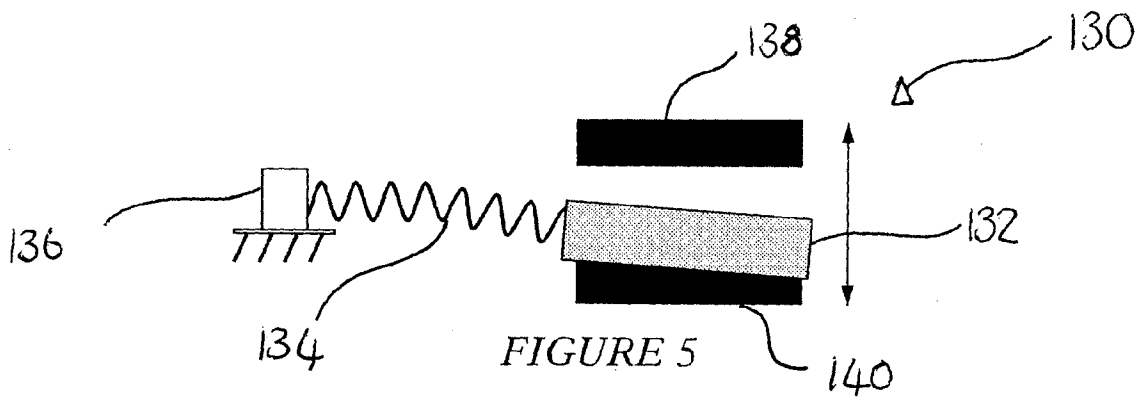


FIGURE 5

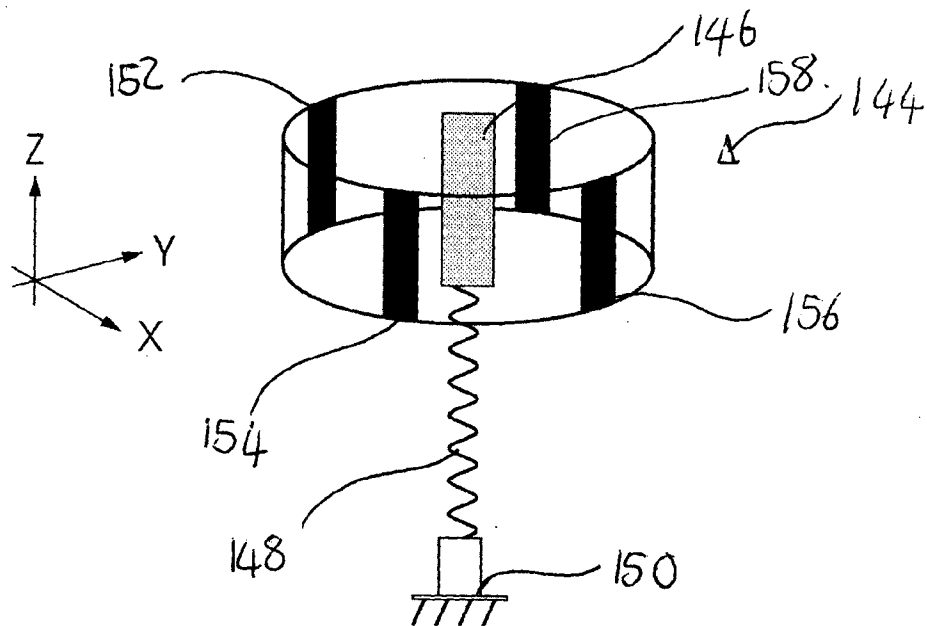


FIGURE 6

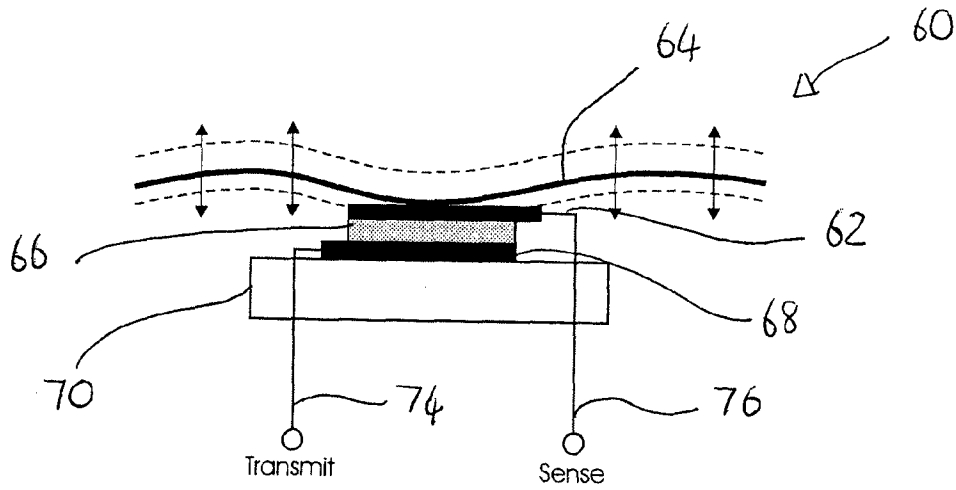


FIGURE 7

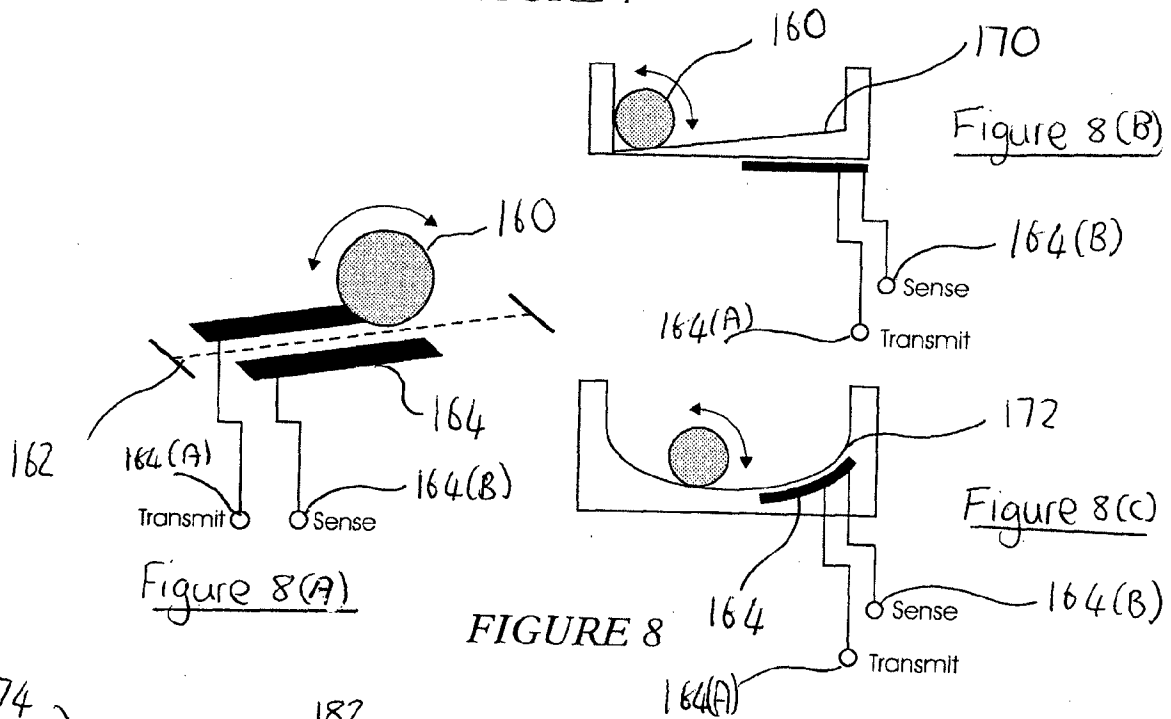


FIGURE 8

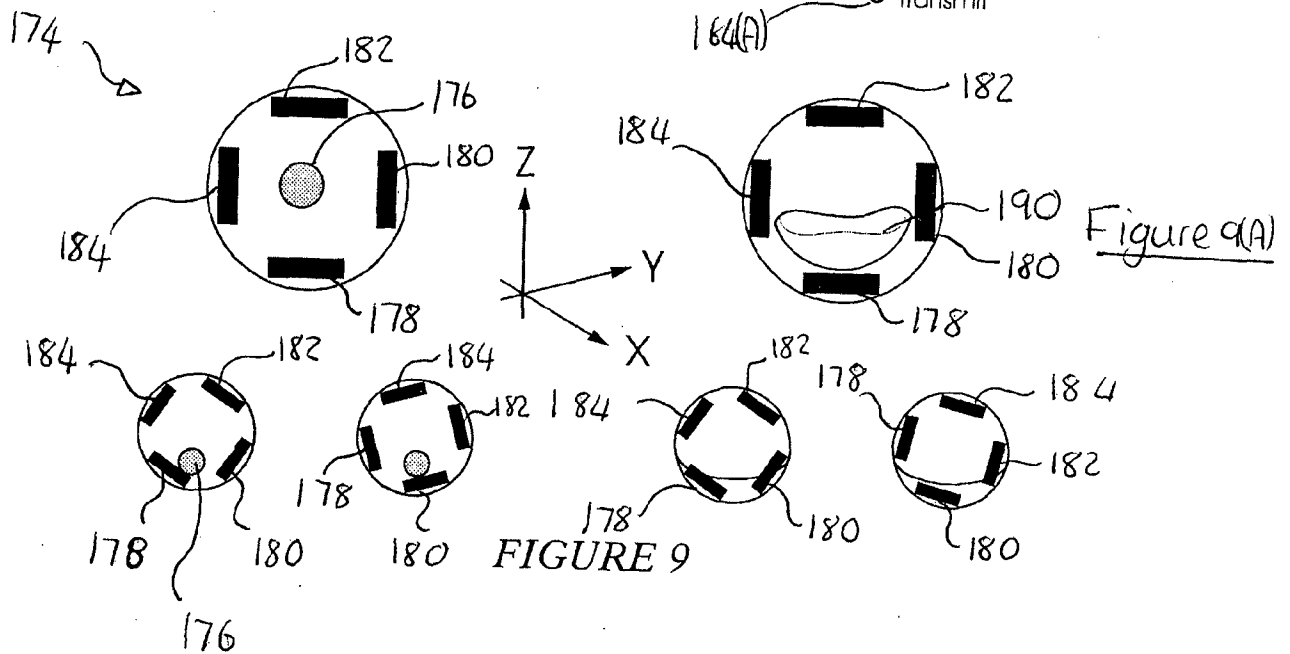
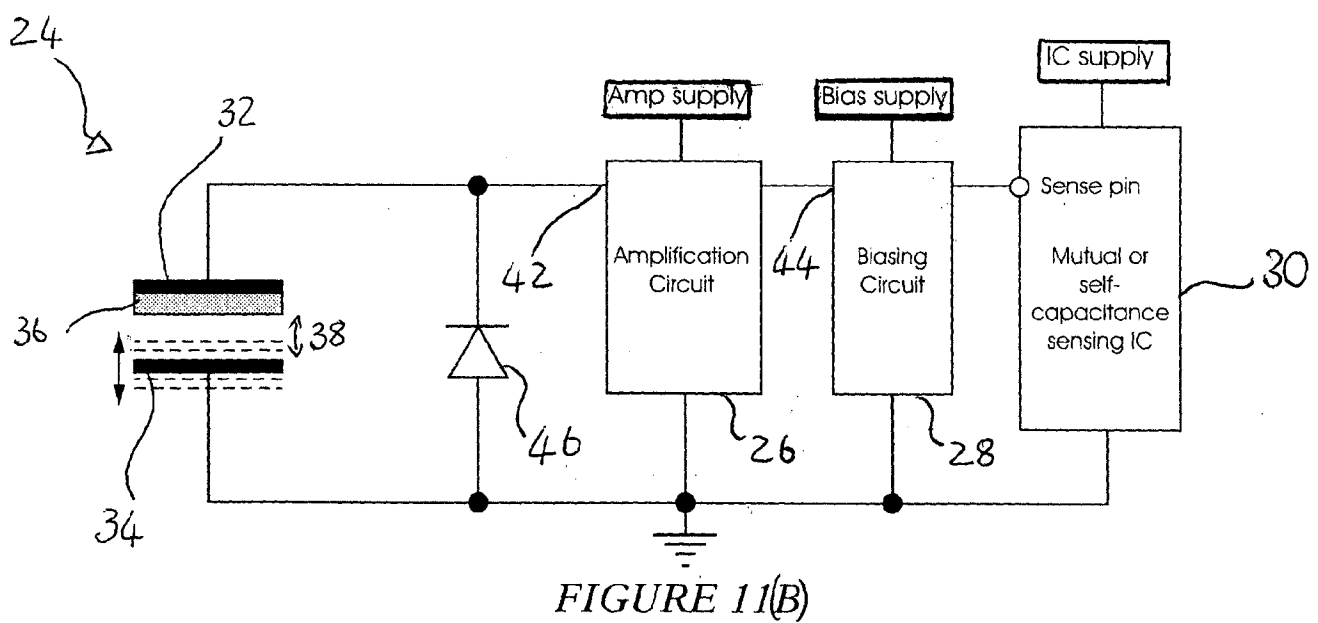
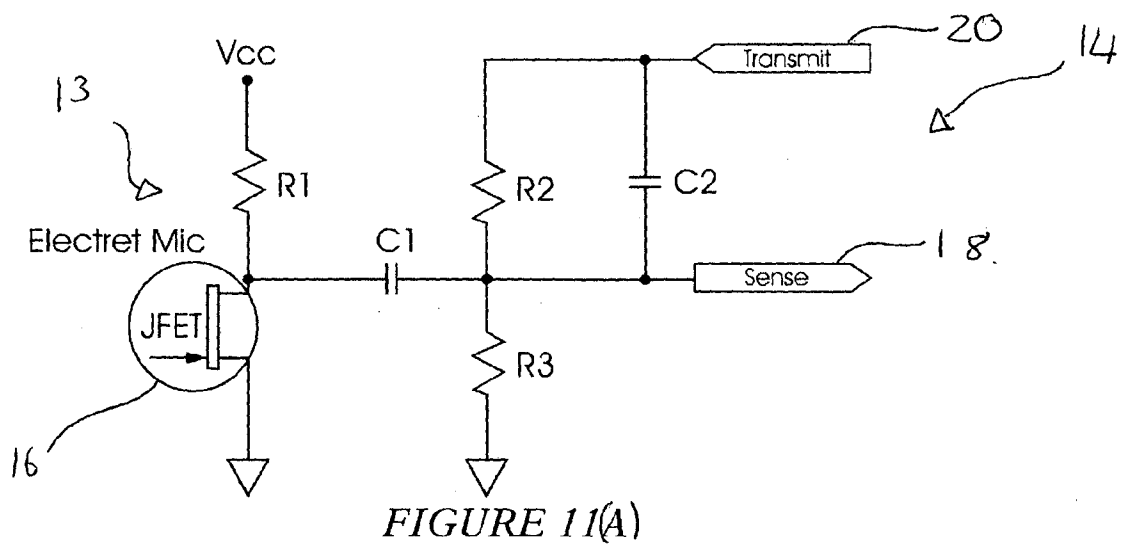
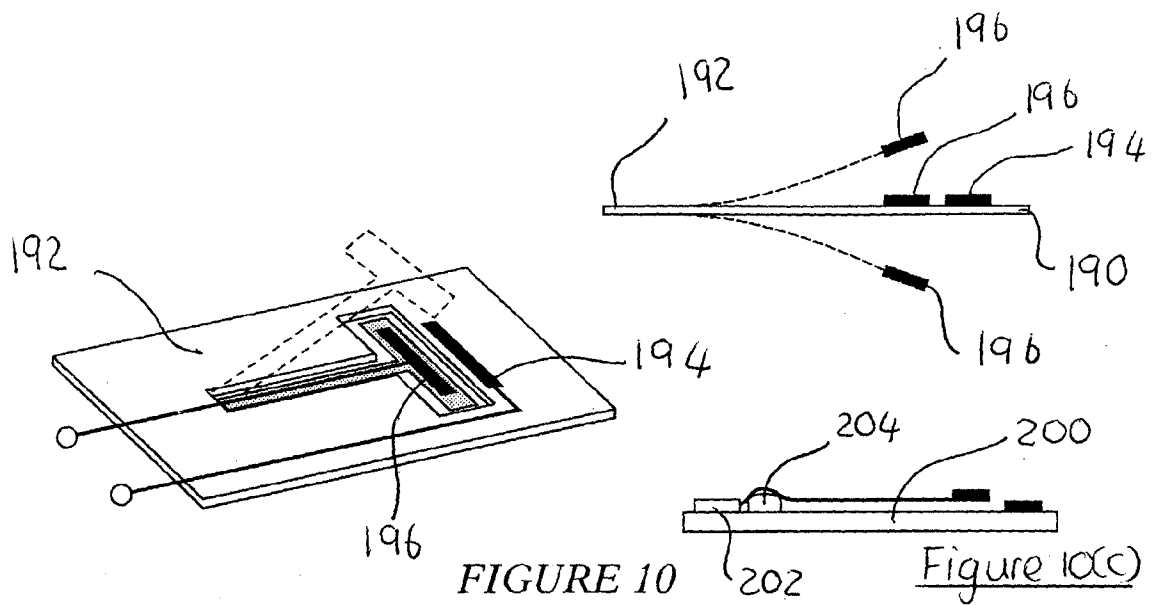
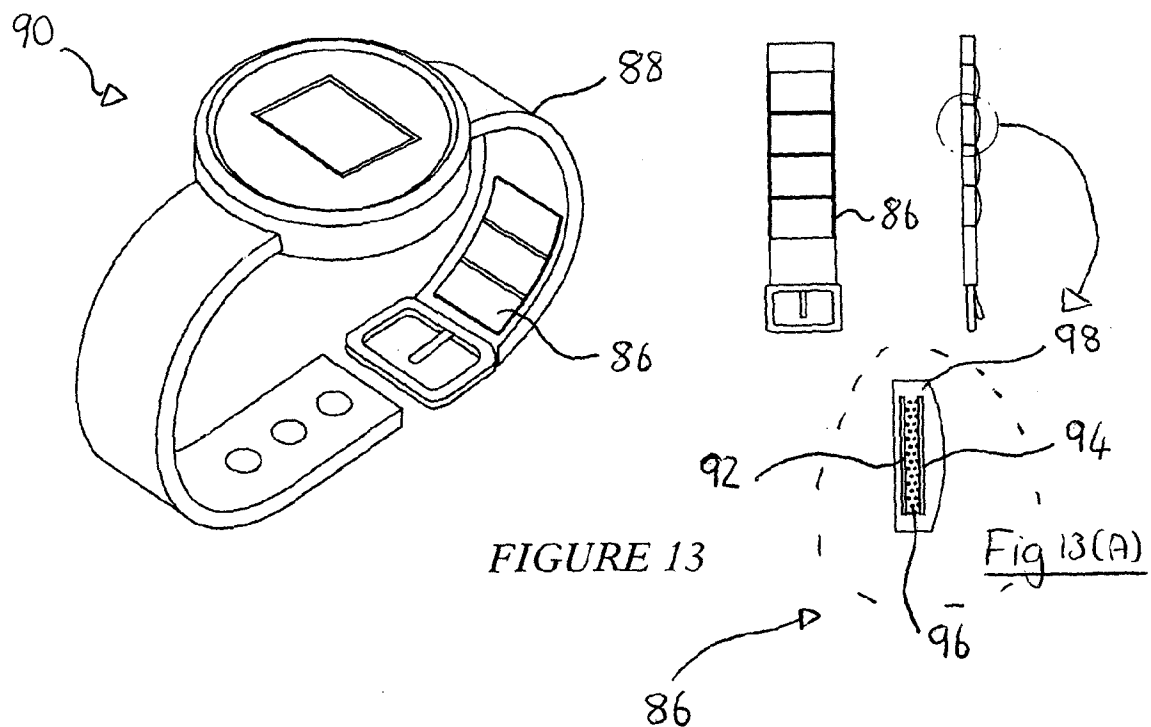
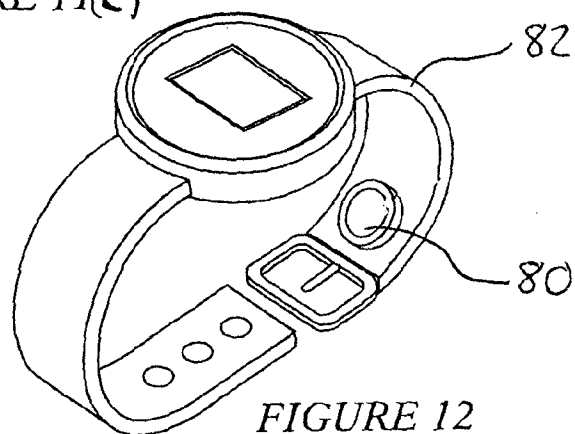
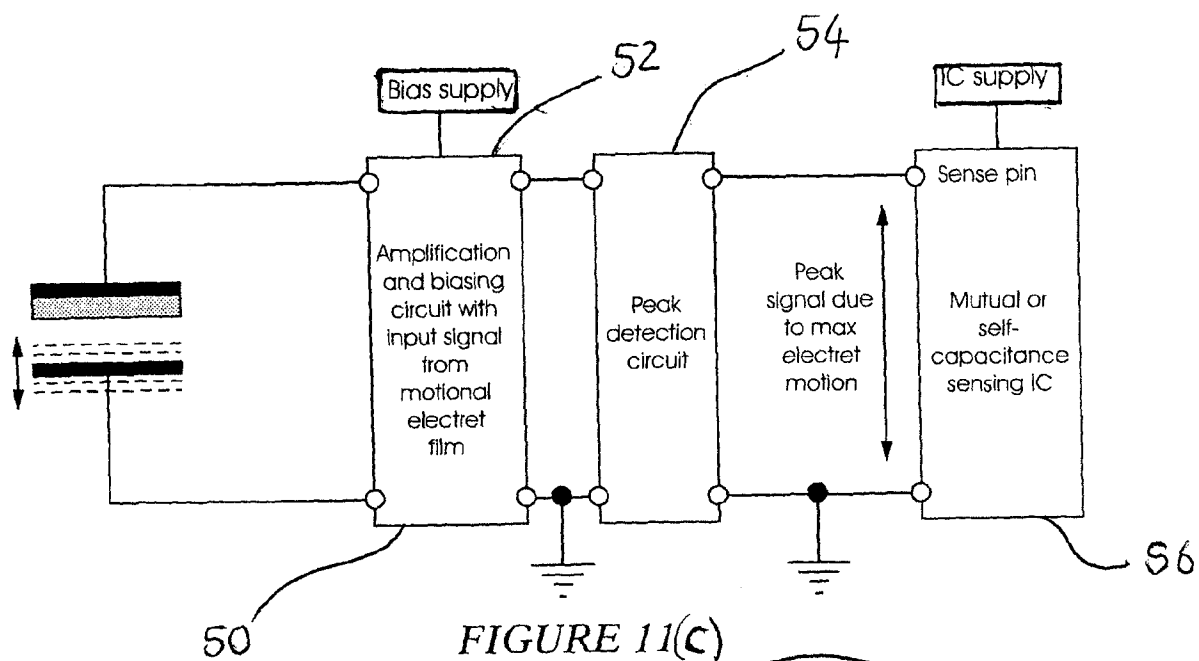
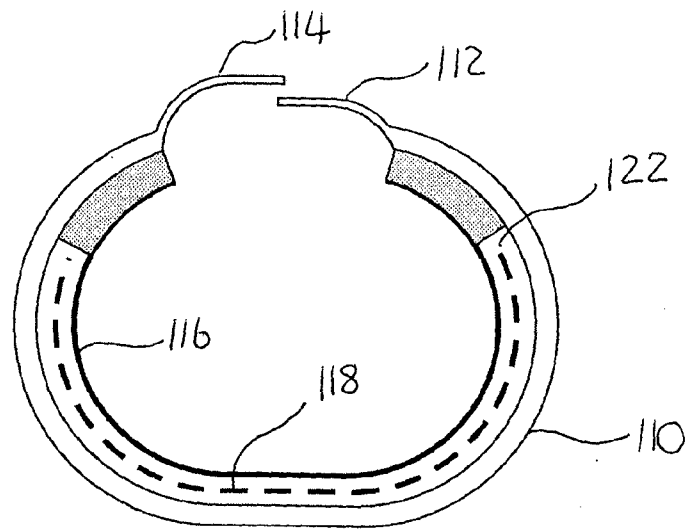
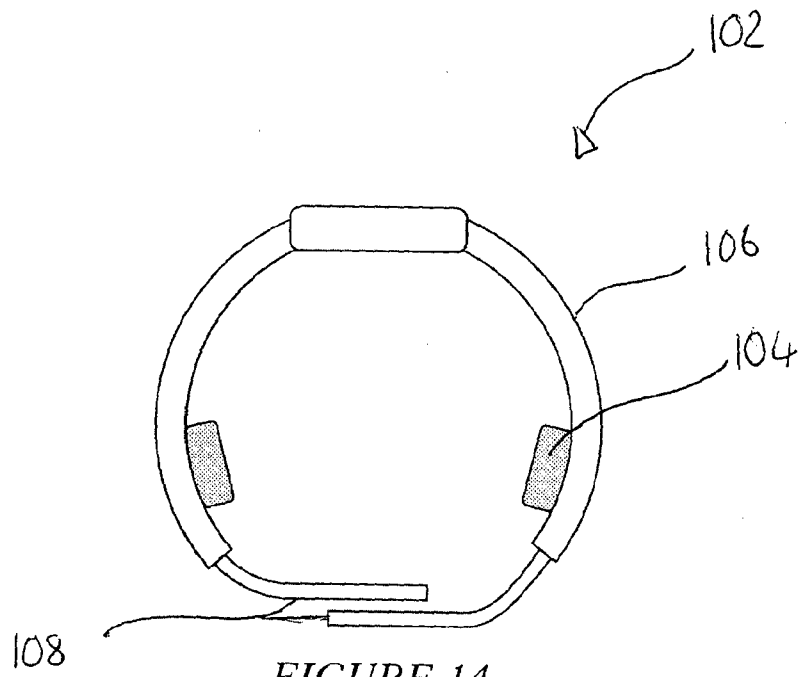


FIGURE 9







INTERNATIONAL SEARCH REPORT

International application No
PCT/ZA2012/000027

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/024
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 491 647 B1 (BRIDGER KEITH [US] ET AL) 10 December 2002 (2002-12-10)	1-4, 6-10, 14-18
Y	column 13, lines 40-44 column 15, lines 11-13,27-30 column 19, lines 62-65 column 30, lines 53-61 column 32, lines 20-47 figures 2,3,12,15,20-23	11,13
X	US 2010/217345 A1 (WOLFE ANDREW [US] ET AL) 26 August 2010 (2010-08-26)	1-6,9, 14,18
Y	paragraphs [0025], [0026], [0030], [0041], [0042], [0047] - [0050] figures 2,3,8,9	12
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Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

30 August 2012

Date of mailing of the international search report

06/09/2012

Name and mailing address of the ISA/

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Worms, Georg

INTERNATIONAL SEARCH REPORT

International application No
PCT/ZA2012/000027

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	----- US 4 409 983 A (ALBERT DAVID E [US]) 18 October 1983 (1983-10-18) figure 9 -----	13

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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