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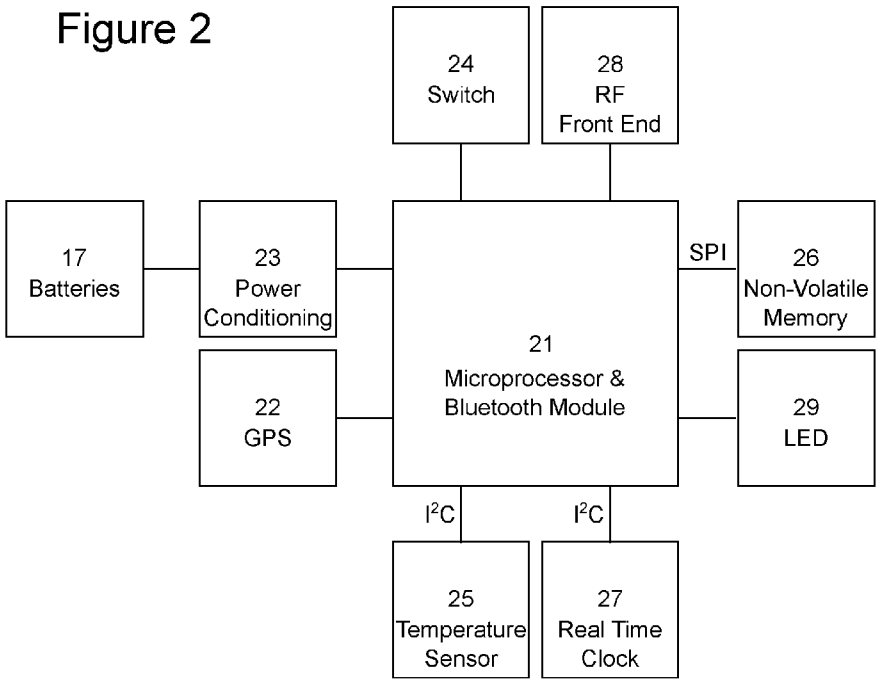
(54) Title: SENSING DEVICE FOR MONITORING A CONDITION OF AN ITEM

Figure 2



(57) **Abstract:** A sensing device for monitoring a condition of an item, the device comprising a sensor for detecting one or more specified conditions associated with the item being monitored, a memory for receiving data from the sensor and recording at least some of the data associated with one or more of the specified conditions of the item, wherein the data to be recorded includes data about one or more alarm conditions which occur when a specified condition passes outside a specified threshold range and a housing for retaining the sensor and the circuit, the housing being configured to be mounted to the item being monitored, further comprising a data output device for receiving data about the specified condition(s) and outputting that data to a remote device.

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SENSING DEVICE FOR MONITORING A CONDITION OF AN ITEM

This invention relates to a sensing device and, in particular, a sensing device for use with packages in transit, wherein it is desirable to monitor one or more conditions of the package during transit.

Many different types of items are transported in a variety of different ways, such as by road, rail, plane or ship. Many of the items being transported would suffer some form of damage or deterioration if exposed to certain conditions. For example, certain food stuffs will need to be maintained at a certain temperature or humidity to preserve the condition of the food stuff. Indeed, fresh items such as meat or fish could spoil if exposed to the wrong conditions. Other items may suffer if exposed to significant shock loads, for example by being dropped or otherwise mishandled, in which case the item could become damaged and therefore unusable or unsaleable.

In many circumstances, the conditions to which the item in transit have been exposed are not obvious to the recipient of the goods. For example, where food stuff needs to be maintain at or below a certain temperature, an unwanted rise in temperature during transit may not be apparent, as long as the goods were at the correct temperature on arrival. Thus, the recipient may accept the goods without knowing that the food stuff may be unsafe for eating. Alternatively, a more fragile item may be transported in a box which, outwardly, does not appear damaged. Flowever, the goods on the inside may still be damaged. It is increasingly common for items to be delivered to a recipient without the recipient actually being able to check on the quality of the goods. For example, parcels can be left in “safe locations” by postal or delivery services; food stuffs may be frozen and appear outwardly fine, but only upon thawing would it become clear that the goods had been exposed to higher temperatures.

This then causes problems for a recipient, as it cannot be shown conclusively where and when the damaged occurred, and therefore who is responsible for the damage. This can lead consumers to be disadvantaged when the damaged occurred during

transit, or to delivery/transit personnel being disadvantaged if the damage occurred after delivery and by the consumer.

US patents US 8126675 and US 7856339 describe inventions relating to sensing systems monitoring applications in sports, shipping, training, medicine, fitness, wellness and industrial production. The inventions specifically relate to sensing and reporting events associated with movement, environmental factors such as temperature and other changing conditions. It describes sticking a shipping label having a temperature sensor and a movement sensor to the product for monitoring temperature and movement events of a product during shipment, via the temperature and movement sensors; time-tagging temperature events sensed by the temperature sensor during shipment that fall outside of a predetermined acceptable temperature range; time-tagging movement events sensed by the movement sensor during shipment that are above a predetermined threshold level; and identifying a location associated with (a) the unacceptable temperature events or (b) the above threshold movement events. Other available products are used for quality control and quality assurance purposes; including chemical change time/temperature labels; electronic devices for use with cold chain shipments such as the Cryopak i-Mini LCD monitor for temperature monitoring and mechanical devices such as ShockWatch's impact monitor for monitoring the shock loading of packages or goods in transit are also known, for use in providing information on what has changed environmentally to products and shipments during transit.

However, although the chemical systems which can be low cost and thus justify single use operation, can provide information on the detail of movements and environmental conditions, integrated over the total shipment period, they cannot provide details of where conditions changed or by how much; the same is also true of mechanical shock impact monitoring devices and so the time and place of exceedance of limits cannot be established. Therefore, the liability of the various parties involved in the chain of transporting and storing packages and goods from one location to another cannot be established, only that exceedances have occurred. Further, although available electronic monitoring devices can timestamp changing environmental factors, they are

usually expensive and require complex logistical processes for commercial success and are not therefore appropriate for use on most single item shipments or where shipments travel around the world in one direction. As such, these monitoring devices cannot therefore be readily returned to their point of origin or provide the owner of goods being shipped with independent data for quality assurance purposes of what has happened to their goods during transit.

Thus, it is desirable to have a system and method addressing one or more of the aforementioned difficulties and in particular to enable a label to be affixed to goods or packages which can be justified on cost grounds for utilisation on a single journey basis and which can be deployed and monitored by unskilled personnel.

According to the present invention there is provided a sensing device for monitoring a condition of an item, the device comprising: a sensor for detecting one or more specified conditions associated with the item being monitored; a memory for receiving data from the sensor and recording at least some of the data associated with one or more of the specified conditions of the item, wherein the data to be recorded includes data about one or more alarm conditions which occur when a specified condition passes outside a specified threshold range; and a housing for retaining the sensor and the circuit, the housing being configured to be mounted to the item being monitored, further comprising a data output device for receiving data about the specified condition(s) and outputting that data to a remote device.

The sensor and the circuit may be mounted on a common structure such as a PCB. The common structure may be readily removable from the housing to allow reuse of one or both of the common structure and the housing. This may be achieved by the PCB or other common structure being press fit into the housing such that the common structure can easily be pulled/pushed out of the housing. Alternatively, it may be achieved by the removal of a retaining element such as adhesive tape or a cover piece, thereby permitting access to the common structure. Alternatively, one or more retaining parts may be split, cut, torn or otherwise altered, for example, the common structure could be ultrasonically welded to the housing and so the removal will be by

cutting all four edges off so the two parts can fall away from each other releasing the PCB.

The device may further comprise a GPS tracker for identifying the actual location of any alarm condition. The device may further comprise a momentary switch for controlling the activation of the sensor. The device may further comprise a microprocessor.

The data output device is one or more of an outlet port or a wireless communication device, which may be one of RFID, Bluetooth, wi-fi, radio or other near field communication device.

The housing preferably includes a rigid shell and/or an adhesive strip.

The device may further comprise one or more batteries, and preferably, wherein at least one of the batteries is located and sized to provide structural resistance to protect the circuit during crushing of the housing towards the item. At least one of the batteries is preferably the tallest component within the housing, thereby providing some impact protection for other electronic components.

The circuit may only record data when a predetermined threshold associated with the condition has been reached. The data recorded preferably include a time stamp to indicate when the threshold is reached.

The memory may record only the first occurrence of the threshold being reached, or may record multiple occurrences of the threshold being reached. The memory may be volatile or non-volatile, depending upon the expected usage of the device and the data recording rules.

The housing may have a hinged section for use in retaining the sensor and/or memory circuit.

The device may further comprise an alarm for providing a visible indication to a user of an alarm condition having been triggered, which may include one or more LEDs.

The device may further comprise an integrated circuit for controlling the device.

The device may form a system together with a smart device application, the application being capable of communicating with the device to obtain the recorded data.

The housing may comprise a relative hard shell with one or more recess portions therein, wherein the recess portions are sealed by a film lid, which may include an LDPE layer. The housing may have two recesses, which may be of the same depth. One of the recesses may include one of more projections for preventing unwanted movement of batteries located on a PCB, which can be inserted into the recess. A rib may be provided between two recesses in the housing. The rib may be structural , and may be sized so as to projected beyond the PCB and its components, thereby reducing the risk of accidental damage or contact with the PCB or its components.

The invention also provides a method of monitoring the condition of an item using a device as described above, the method comprising interrogating the memory of the sensor device to obtain data associated with the condition of an item to which the device has been attached by using an application loaded onto a smart device; and communicating with a remote system using the application to record the condition of the item.

It is further desirable to provide methods and devices that are able to quantify changes in environmental conditions, movements, shocks or other factors affecting an item and to readily identify to appropriate personnel when these conditions have exceeded pre-set limits and to report meaningful environmental change information to interested parties. This is preferably via Smart devices to the Information Cloud for monitoring and control purposes.

The present invention will now be described by way of example with reference to the accompanying drawings. In the drawings:

Figures 1a to c shows a schematic representation of a first sensing device from various angles;

Figure 2 shows a schematic representation of some of the electronic components mounted on a PCB;

Figure 3 shows one form of a possible housing;

Figure 4 shows a further form of housing;

Figure 5 shows the housing of Figure 4 mounted on a label;

Figures 6a and 6b show a sensing device mounted on a self-adhesive sticker;

Figure 7 shows a circuit diagram of a power control circuit for use in a sensing device;

Figure 8 shows the shockwave that could be sensed by an accelerometer; and

Figure 9 shows another form of housing for a PCB.

Figures 1a to c show a sensing device 10 having a front face 11 and a rear face 12. The device is formed from a housing 13 having a hollow portion 14 extending away from the front face, the hollow portion defining an enclosure 15 in which electronic components are mounted on a printed circuit board (PCB) 16.

The PCB contain various components shown in more detail in Figure 2, but specifically contains a pair of batteries 17, one on each end of the PCB. The batteries 17 are the tallest components, in that they extend the furthest from the PCB in a direction away from the front face, such that the batteries can absorb some of the load or shock applied by an impact towards the front face, thereby protecting other more delicate components.

The housing is provided with a tab 18 at a first end 19 of the housing. The tab may be a flexible element and is provided to assist a user in removing the sensing device from an article or item to which it has been attached.

Figure 2 illustrates an example of the electronic components forming the sensing device 10. The sensing device includes a microprocessor 21, which preferably

includes Bluetooth or other wireless communication protocols to enable the sensing device to communicate with one or more remote devices. The microprocessor is connected to a power supply, typically in the form of the pair of batteries 17 shown in Figure 1, via a power conditioning circuit 23 (shown in greater detail in Figure 5) which controls when and how power is supplied to the microprocessor to maximise the life of the power supply. A GPS or other cellular triangulation 22 is also provided to assist in identifying the location of any alarm condition.

A switch 24 provides user control over activation of the device and an RF transmitter front end 28 connects to the Bluetooth part of the microprocessor 21. A temperature sensor 25 is connected via an I^2C link to the microprocessor, as is a real time clock 27. A non-volatile memory 26 and an LED 29 are also connected to the microprocessor. In one example, the switch powers on the device from shelf mode and from that point on it activates the Bluetooth communication for one minute. The reasons for this are firstly to save battery power and secondly to ensure there is no radio interference being generated should the tag be in an aircraft hold or similarly restrictive environment. Further explanation of the switch is provided later.

In one example, a temperature sensor 25, such as a thermistor, is mounted on the PCB 16 and connected to an Analogue to Digital Converter (not shown) incorporated within the microprocessor 21 for monitoring the temperature of the surrounding environment. The temperature sensor could be a Platinum Resistance Thermometer or Thermocouple. Alternatively the temperature sensor could be a silicon based temperature sensor with either an analogue voltage output which is proportional to the temperature or a quantised value transmitted digitally over a data bus to the microprocessor. The temperature sensor could be replaced by any type of sensor that detects a change in environmental conditions that might affect an item. Such conditions include temperature, humidity, impacts, shocks, ambient pressure, the presence or absence of a particular gas especially the presence of a combustible gas, magnetism, radiation or light, and so all references in the specification to “temperature” sensor should be understood to include any other suitable sensor and any reference to “temperature” should be understood to include whichever condition is to be sensed.

The microprocessor also contains a microwave frequency radio transceiver 28 suitable for communicating with a smart device such as a Smartphone or tablet. The PCB assembly also includes a non-volatile memory integrated circuit 26, a momentary switch 24 and an indicator light 29 such as a light emitting diode (LED). The PCB assembly is incorporated into a housing structure 13 which can be stuck, or otherwise mounted, fixed or connected, to an article or packaging surrounding an article or group of articles, such that the label experiences the environmental and movement changes of the article or package. The housing structure 13 is preferably rigid, at least in part and in particular in the hollow section 14, to assist in protecting the electrical componentry. The housing 13 may be fixed directly to an item or group of items being tracked, for example by adhesive or other fixing means. Alternatively, the housing may be mounted on a sheet or label 40 (shown in more detail in Figure 4) which is itself then affixed, by way of a self-adhesive sticker 41 or other fixing means, to the item or group of items being tracked. The sheet or label may be flexible, and the housing may include one of more flexible sections to permit the sensing device to be mounted more securely on a surface which is not planar.

Further, the microprocessor can be programmed to commence logging the temperature measured by the temperature sensor of the surrounding environment once the momentary switch 24 has been depressed or after a factory pre-set delay and to store the temperature at a particular elapsed time in the memory integrated circuit 26. The microprocessor 21 also compares the measured temperature against factory pre-set limits to identify if any alarm events occur where the PCB assembly and thus the goods or packaging have been exposed to temperatures outside these limits. If exceedances have occurred either instantaneously or for pre-set periods then an alarm can be activated. For example, the LED 29 can be flashed continuously or an audible sound generated to identify to any personnel involved in the transportation and storage chain that an exceedance has occurred. It will be recognised that at the point of commencing logging, the article or packaging may not be subject to the environmental conditions that it is expected to be transported in and, as such, it is an option that the environmental condition exceedance alarm will not be activated until

the sensor has detected that the environmental condition has been reached by the article or packaging for a specified period of time. For example, a package which, after affixing the label, is placed in a refrigerated transportation container will typically log from the point of activation, but may only trigger the exceedances alarm LED after it has determined that the environment inside the refrigerated transportation container has reached the level at which it is designed to remain.

Further, the system incorporates an application running on a smart device such as a smartphone or tablet computer which can be used to interrogate the sensing device to acquire the temperature vs. time data and to display it on the smart device to indicate where the exceedance occurred and to enable this data to be uploaded to a computer server via the internet for control and monitoring purposes. The location information could be provided by taking information from the GPS 22 or alternatively the recorded time on the tag for any alarm condition can be correlated with the shipping information provided by the courier. To conserve battery life for the label, communication could, for example, only be enabled when an exceedance has occurred or when the momentary switch has been depressed, and remain enabled either for a period of time or indefinitely.

Activation of the momentary switch can also be used with multiple pushes to indicate other desired operation changes on deployment of the label to the microprocessor, such as changes to the temperature limits, delay time before alarm monitoring commences etc. Equally, the frequency or duration of the LED flashing, or of a sound being generated, can be used to indicate on deployment, or after exceedances, different modes of operation of the label or severity of exceedances. At the point of deployment of the label, it may also be desirable for an operator with a smart device to upload to the microprocessor differing values for temperature limits or periods or delays before logging commences. At this same point of deployment, it may also be desirable for an operator to associate the particular label with an internal shipping or tracking number. This can be done in one instance by entering the shipping or tracking number into the application so that it can be communicated to and stored digitally on the label and in another instance by the application communicating the association

between the particular label and the entered shipping or tracking number up to the remote server for storage. The entry of the shipping or tracking number can be made manually by the operator or automatically by the application scanning a printed code such as a tracking or shipping label or alternatively scanning a wireless Radio Frequency Identification (RFID) device affixed to the article or packaging. Once the article or packaging has reached its destination, the stored association of the tracking or shipping number and the label's unique identity, can be retrieved by an operator running an application on a smart device such as a smartphone or tablet computer that can scan the printed code or RFID device in order to facilitate a wireless connection with the label in the instance that there are many wireless labels within range and to verify that the label hasn't been replaced with another in the case that somebody wanted to substitute a record of the environmental conditions where the article or packaging has experienced exceedances with a benign record.

It will be obvious to anyone skilled in the art that the microprocessor and the communication integrated circuit may be implemented on a single integrated circuit assembly such as a System on Chip (SoC) to reduce the size and cost of the PCB assembly.

Figure 3 illustrates one form of a housing 13 which could be utilised. The housing 13 takes the form of a clam shell, that is a front section 30 and a rear section 31 which are joined by one of more hinges 32. In this example, the front and rear sections and the hinge are formed in a single piece of material, typically PET plastic, such that the hinge 32 runs the full length of the join between the front 30 and rear 31 sections. The hollow section 14 is formed in the front section 30 and, by folding at the hinge 32, the rear section 31 can be brought into contact with the front section 30 to form the enclosure 15. The rear section is provided with one or more protrusions 33 which are for engagement with respective edges of the PCB to retain the PCB in place. Typically, the PCB can be push fit onto the housing, i.e. the protrusions define a space slightly smaller than the respective dimension of the PCB. The ridge 33 may be a single continuous ridge substantially forming a ring which encircles the PCB. Alternatively, two or more discrete protrusions may be provided. The protrusion(s) may be on the

rear section as shown in Figure 3, or may be provided in or around the enclosure 15 within the front section. This option is particularly useful in an alternative housing construction shown in Figure 4 which does not require the rear section 31. In such a construction, the housing may simply have an outer rim section 45 within which the hollow section 14 is formed defining enclosure 15. The PCB 16 can be press fit into the enclosure as shown in Figure 5 with protrusions 33 being provide on the inner side walls of the hollow portion 14. The enclosure can then be sealed by an outer layer 40 which may include one or more adhesive areas for affixing the sensor to an item to be tracked.

Figures 6a and 6b show how the housing of any of Figures 3, 4 or 5 could be mounted in label or sticker structure. The housing 13 is retained between two layers - a first front label layer 60 and a second rear adhesive layer 61. In Figure 6, the housing 13 is shown without an additional layer such as rear section 31 or outer layer 40, to close the enclosure 15, but rather the closing of the enclosure is provided by the adhesive layer 61.

The example structure of Figure 6 is one that helps to ensure that the label assembly can be manufactured in high volume and at low cost. The adhesive layer 61 may be a double sided adhesive tape with a peelable backing layer which is removed by the user when the label is deployed onto the item or packaging. The housing of Figure 4 also helps to ensure that the label assembly can be manufactured in high volume and at low cost as it is preferably a vacuum moulded preform which is produced as a strip of a number of assemblies and accomplishes a number of functions. Firstly, it is so designed that the PCB assembly can be clipped into it (for example by way of protrusions 33) during the assembly operation to ensure that when the preform is brought down into contact with the upper layer of the double sided adhesive tape, the PCB assembly is retained in place and does not drop out. Secondly, it is so designed that it will assist the adhesive layer which will ultimately bond to the underside of the PCB assembly in ensuring that the forces experienced by the label assembly when bonded to an item or its packaging are reliably transmitted to the PCB and that regardless of any changing environmental conditions the PCB assembly cannot move

around within the preform. Thirdly, the preform provides the necessary environmental protection for the electronic components, such as protection from excessive moisture ingress, damage by external forces or electrical interference by external bodies. In some instances for the protection of electronic components from the effects of light, it may also be of, for example, a translucent nature, allowing the visual indicator such as the LCD to be seen but obscuring some of the light impacting the label from entering. In yet other applications for example for gas sensing, the preform may have formed into its surface, micro-pores to allow gas molecules to penetrate into the PCB assembly cavity to reach the sensors. Further, the preform has additional features moulded into its top surface to facilitate the user readily depressing the PCB mounted momentary switch to accomplish deployment of the label in use and provide other inputs if required to the microprocessor. Finally, the preform and the PCB assembly are so designed such that the battery or batteries are the tallest component and are so positioned on the PCB such that frontal impacts to the label assembly during use will not be transmitted to the other components on the PCB. The preform may be further designed with cut-out features at each end of the label pitch such that when a printed label top cover 60 is applied over the preform onto the double sided adhesive tape, the printed top cover 60 is adhered to the tape substantially all of the way around its four sides, as shown in Figure 6b, whilst still allowing the assembly process to be carried out as a reel to reel process with the individual label separated by a guillotine operation at a later stage or as a manual assembly process where for example 10 labels are produced at one time with pre-cut preforms of a suitable length.

A further example of a housing 100 is shown in Figure 9. The housing 100 consists of a relatively rigid shell 101, typically formed from a PET plastic and similar in form to that of previous examples, and containing two hollow recesses 102 and 103 surrounded by a flanged edge 108. Hollow recess 102 is for retaining, in use, the PCB 104. To assist with this action, the PCB 104 is preferably press fit into the hollow recess 102. The press fit nature is typically achieved by the provision of one or more projections 105 which define an area slightly smaller in at least one dimension to that of the PCB, such that the PCB can be pushed beyond the projection(s) 105 deeper

into the hollow recess 103. The projection(s) 105 typically form a lip over which the PCB can be forced during insertion into the recess 102.

Further projections 106 are provided, in this example one at each end of the recess 102. These projections do not need to form a lip, but are intended to abut, or at least closely align with, the respective ends of the PCB 104. The purpose of the projections 106 is to prevent the batteries, as shown in Figure 6 for example, from being dislodged from any holder on the PCB, but yet still permitting sufficient space with the recess 102 such that the PCB can easily be inserted and removed for recycling purposes.

Recess 103 is substantially the same depth as recess 102 and is provided to allow housing 100 to be more securely fastened to an object being monitored, as it is the bottom of the recesses (the right-hand side of the side elevation) which is placed against the object. Recess 103 is typically empty, but is provided with a slightly convex outer lower surface to increase its rigidity and permit better adhesion to a surface on which the housing is applied. The need for the convex surface only arises on recess 103 as it is empty. Recess 102 has a relatively higher rigidity in use due to the presence of the PCB.

After insertion of the PCB, the recesses 102 and 103 are sealed by a lidding film 107 which is heat sealed onto the outer edges 108 of the housing 100 to define a sealed chamber in which the PCB is located. A label may be applied on the outer surface of the film, but more preferably the labelled in placed inside the housing, on top of and covering both recesses, and is then sealed in place by the film 107. The label may or may not be adhesive, and the housing may include a label recess 110, the label recess 100 being slightly larger in at least one dimension than an area enclosing both recesses 102 and 103, thereby preventing the label from falling into one of the recesses. The film 107 and/or the flanged edge 108 includes an LDPE layer which melts under pressure to create a hermetic seal of the film 107 to the flanged edge 108.

The two recesses 102 and 103 are separated by a rib 109, which is a region of reduced depth compared to the recesses. This rib provides increased structural strength to the

product. Furthermore, in the expected orientation of the PCB, the switch 24 referred to in previous examples is typically located adjacent the rib, and therefore by ensuring that the rib is taller that the upper end of the switch when the PCB is installed. By taller, we mean that the top of the rib 109 is closer to the level of the opening to the recesses 102, 103 than the top of the switch, such that the rib helps to prevent accidental operation of the switch 24. The rib may be level with flanged edges 108, or may be at the same level as the label recess 110.

Battery lifetime is paramount in a device such as the present invention and therefore it is preferable for the sensing device to include a circuit of the form shown in Figure 7. Furthermore, in order to enable a long shelf life for the sensing device prior to the first use and therefore the first activation, the label preferably enters a "shelf" mode after production, whereby power is disabled to all digital circuitry. This can be achieved by using a P-Channel enhancement Metal Oxide Semiconductor Field Effect Transistor (MOSFET) 71 whose gate is connected via a large value (e.g. 10 Megaohm) resistor 72 to the battery positive supply as well as through a push to make switch 73 to the battery negative supply 74. Switch 73 is preferably the same as switch 24, but may be an additional switch. When the switch 73 is not pressed, the MOSFET's gate 71 is below the gate threshold voltage difference required to enable the MOSFET to allow current to flow to the digital circuitry 75. Once the switch 73 is pressed however, the voltage at the MOSFET gate 71 drops to battery negative 74 or 0 volts and the gate threshold voltage differential is now above that required for the MOSFET to allow current to flow to the digital circuitry 75. The microprocessor 21 then starts to execute its programme and early on in that programme it drives, to a voltage level that is sufficiently high to turn on N-Channel enhancement MOSFET 78 (such as 1V), a digital output 77 that is connected to the gate of MOSFET 78. MOSFET 78 is connected in series with a resistor 79 of significantly lower value than resistor 72 (e.g. around 1% of the value of resistor 72 - thus if resistor 72 was l OMegaohm then resistor 79 would be 100 kiloohm), that is connected to the gate of the P-Channel MOSFET 71. This resistor 79 and N-Channel MOSFET 78 are connected in parallel with the push to make switch 73 so that when the switch is released by the operator, the two resistors form a potential divider wherein the voltage at the gate of the P-

Channel MOSFET 71 rises slightly above the ground voltage but not enough to turn the P-Channel MOSFET (1) off, thereby disabling the digital components 75. The effect of this operation is that that the power can be retained to the digital circuitry 75 by the programme running on the microprocessor 21. Additionally however the voltage at the P-Channel MOSFET's 71 gate can be read by an Analogue to Digital Converter, typically located on the microprocessor 21, to determine whether or not the switch 73 is being depressed. In the event that it is, the voltage measured will be below a few millivolts but when it is not, the voltage will be close to the calculated voltage midpoint of the potential divider circuit 80. The switch 73 is therefore dual use and is used to instruct the microprocessor 21 to activate the radio. This activation may be permanent, or may be for a limited period of time, for example on labels that must not transmit radio during transit for reasons of aircraft safety or regional radio regulatory compliance. In order to conserve battery capacity, the microprocessor 21 remains in a low power mode for the majority of the operational time, waking up to service the radio protocol or to take a temperature reading. An average quick press of the switch 73 will take only around 100ms whereas the microprocessor 21 might be in low power mode, and not measuring the switch 73, for a second or more. In order to ensure that even a brief switch press is registered by the microprocessor when it eventually wakes up, a large capacitor 81 is placed in parallel with the lower value resistor 79 and N-Channel MOSFET 78. Once the switch 73 is pressed, the capacitor 81 is discharged very quickly and is then recharged slowly from the large value resistor 72 at the top of the potential divider. As a result the voltage level at the midpoint of the potential divider will take a relatively long period of time (typically between 1 and 10 seconds depending upon the value of resistor 72) to reach its previous level allowing time for the microprocessor 21 to wake up, measure and determine that a switch 73 press has taken place.

When no power is connected to the system, and then the switch 73 is used to turn on transistor 71 to the system. From thereon all the switch does is drop the voltage level at 80 from around 1% of the battery voltage to 0% of the battery voltage. This voltage drop can be detected by the analogue to digital converter on the microcontroller 21 and used to indicate to the software that the switch has been pushed. There are two

ways to read the voltage level; the first is by reading the voltage level periodically (known as polling) as a result of a timer expiring in the software and the second, preferable method, is to use a comparator which is a small circuit that waits until the voltage at 80 crosses a threshold (i.e. 0.5% of battery voltage) and generates a digital on/off signal that can trigger an interrupt on the microcontroller. When using the polling option, the large optional capacitor 81 would ensure that the voltage level at 80 coupled with the very low charging current (due to the high value of resistor 72) would rise slowly enough that the polling period could be up to 1 second.

Temperature readings are written to the non-volatile memory integrated circuit and space can be saved in the memory by either logging only temperature results representative of exceedances of the alarm limits along with a timestamp recording the time of the exceedance and the duration of the exceedance before the temperature returned to within alarm minimum and maximum limits. It will be obvious to a person skilled in the art therefore that in addition to just logging exceedances, logs consisting of a minimum and maximum temperature, a timestamp and a duration that the temperature remained within these bands can potentially reduce the amount of data stored at the expense of quantising the samples into temperature bands. It will also be obvious to a person skilled in the art that should the amount of log data be reduced for a given period of operation then this can be stored internally to the microprocessor in either non-volatile or volatile Random Access Memory (RAM) so reducing the number of components on the PCB and power consumption during operation.

A GPS tracker 22 is also preferably provided as part of the sensing device. The GPS tracker is also in communication with the memory such that any activation of an alarm condition can not only be time stamped, but can alternatively or additionally be linked to a physical location. This can allow further detail about an alarm condition to be known and, given the accuracy of GPS system to within a few metres, this could vital in determining who was responsible for the item at the point at which the alarm condition and potential damage to the item occurred.

In the present invention, the timestamp stored is not a time since an epoch such as the 1st January 1970 is commonly used in computing, but instead a counter incremented at regular intervals. At the point at which the data is retrieved from the device, the current value of this counter is read by the smart device that then subtracts the current counter value from the current absolute time in order to determine the epoch for the particular tag; the epoch being the time since the device was powered up out of "shelf mode.

At time of PCB assembly, the device's microcontroller 21 is programmed with custom embedded software and a unique MAC address, assigned out of a purchased block allocated by the regulatory authority, the IEEE, as well as some other permanent information such as crystal trimming values or other values that are specific to each manufactured unit that could include, but is not limited to, a calibration or adjustment value for the environmental sensors to suit specific customer requirements.

After the PCBs are programmed and tested, then they may be held in stock until ordered or called off by a customer. When the customer orders a quantity of devices through a web interface or through a customer service agent, then either they, or the customer service agent, digitally specify the configuration of the device including alarm limits, the time period between the temperature or environmental value being logged and any other of the configuration variables that the device supports. The customer or customer service agent then takes a quantity of devices from stock and inserts batteries into the battery holders. They then insert a paper insert containing branding of the product, optionally branding of the customer, regulatory or instructional information about the product and details of the custom configuration, such as alarm limits or unique identifiers, that the particular device is configured with, into the vacuum formed casework and hermetically seals the casework using a machine such as an ultrasonic welding machine. The customer service agent then places the quantity of devices within an externally RF isolated box that contains a Bluetooth™ or other wireless transceiver that is connected to a PC. The PC, under operation from the customer service agent, runs a programme that listens for the radio signal from each device within the box and, in turn, connects to them to read parameters such as sensor

outputs and the result of power on self tests and writes the configuration information discussed above to the device, some of this configuration being chosen by the customer to suit their specific monitoring application others being contextual data such as the current date and time or sensor calibration adjustment values. At the same time, the temperature or other environmental parameter that the device is recording is retrieved by the PC and recorded against the unique MAC address identifier of the particular device and an independently value measured by the PC to establish the variance due to manufacturing tolerances of the environmental sensors of each device. Other data recorded on the PC is the unique identifier of the customer to whom the device has been allocated, information about the customer service agent, the time and date that the device has been configured and any other data pertinent to the operation of the device. This data recorded for each device is then transmitted by the PC over a network up to the cloud based server which is the definitive controller of such data. The device is then instructed by the PC to enter the low power shelf life mode in which it reduces its power as much as possible, whilst still allowing the real time clock to run and sensors to be read at a reduced rate. In this mode, data is logged at a minimal rate, perhaps once every hour, so that in the instance where a device was affixed to a shipment but accidentally not activated using the switch, then there would be some environmental sensor data logged; if the switch is pressed however then this previously logged data is wiped from the memory and the device operates with the configuration parameters programmed.

An important part of the invention is the ability for devices to be recycled to reduce the environmental impact of an otherwise one time use device. Since the electronics used should last well beyond the lifetime of the batteries, the devices can be returned to the manufacturer, the caseworks easily removed with the use of a guillotine or other cutting device to be recycled, the paper inserts removed at the same time for sending off to be recycled and the batteries removed from the device also to be sent for recycling. The remaining circuit boards can then be returned to stock to be selected for new orders. Once selected for an order, fresh batteries are inserted and the device is assembled by a customer service agent as already described for newly manufactured PCBs. The device embedded software, when powering up for the first

time however reads the memory of the device and detects that this device has been previously used. When the device is placed into the externally RF isolated box and the PC communicates with this recycled device, the logged environmental sensor data is first retrieved over the radio connection and sent up to the cloud based server in case the previous customer didn't successfully retrieve their environmental sensor data. Thereafter, the same process is followed as for newly manufactured PCBs however when the firmware is instructed to enter the low power shelf life state, then the old environmental sensor and other configuration data is erased prior so that at the end of this process, all devices are in the same state.

In the low power shelf life state, the tag cannot have its configuration parameters overwritten to prevent tampering.

The mobile application runs on a smart device such as a smartphone or tablet and, in its most basic incarnation, is a conduit for retrieving data from the label and uploading that data to the cloud based server. The mechanism for retrieving data in one incarnation is Bluetooth™ but could also be Wi-Fi, Ultrawideband (UWB), Near-Field Communication (NFC), cellular or any other wireless technology. The mobile application searches for a device that is broadcasting a signature unique to the product and from thereon initiates a connection to it, if the radio technology is Bluetooth™ then this broadcast signature could be an Advertising Packet and the unique identifier a Service UUID unique to the device family. Once a connection has been initiated then metadata such as a unique identifier, the alarm limits, the current temperature, operational status, timestamps denoting time and date of manufacture, time and date that logging was started, current time and date for the purposes of determining the device's clock drift so that timestamps relating to data can be de-skewed and other statistics and indicators about the device and what's happened to it since logging of data was started. The application can then use this metadata to determine whether or not the tag has just been activated, perhaps hours previously, or whether it has been logging for days or weeks. Once this determination has been made then the application can automatically show a screen suitable for either of the 2 types of operation that can be performed. These operations are firstly, if the device has only

recently been activated and therefore hasn't yet begun its transit, an opportunity to configure alarm limits, add additional customer information such as a shipping number, add a digital watermark or signature, correct the current time that the real time clock on the device is keeping or a number of other operations related to changing the way that the device operates whilst in transit or any other information that needs to be placed with the device for retrieval at different points within the journey such as, but not limited to, other information about the point of departure. Additionally data can be recorded that is not intended to be written to the device, but can be associated with the device and uploaded to the cloud based server. Such data could be a time and date, GPS location, note, photograph or video created by the operator at the point of departure and is uploaded to the cloud based server for the purposes of providing some context to the shipment's owner about its condition or some verification that the shipment has departed. The second type of operation is if the device was activated some time ago, such as longer than 1 hour. In this operation a screen is displayed indicating that a retrieval of the environmental sensor data is underway and in the background the application is retrieving said data over the radio link. When the data retrieval is completed then all retrieved metadata and environmental sensor data is sent over a network to the cloud based server.

When data is received at the cloud based server, the programme running on the server saves it to a data store such as a database and then informs any registered interested parties, as determined by the customer who purchased the devices originally, that data has been retrieved and whether alarms have been triggered. These notifications could be in the form of e-mails, automated voice calls, SMS text messages, mobile device push notifications or posts to social media accounts but are not limited to these mechanisms. The cloud based server can also correlate the time indexed environmental sensor data with any time indexed information about the location of the shipment, as retrieved either from an onboard location technology on the device, or alternatively based on data received from a third party such as a courier or shipping company's tracking system. This data can also be shared, at the request of the customer, with any third party perhaps for the purposes of indicating that an exceedance has taken place.

Optionally, information received through the app can be correlated with other data sets such as worldwide weather or environmental observations. This correlated data set can further be analysed using machine learning algorithms to identify and predict shipping routes that are subject to environmental exceedances at particular times, thereby enabling customers to consider different methods of shipping to avoid such exceedances.

It is also obvious that the label could incorporate additional or alternative sensors to monitor other or any combination of environmental parameters such as temperature and humidity for ensuring that for example pharmaceutical products are not damaged. For fresh produce the monitoring of temperature and impact loads may be desirable. For some products the monitoring of gases in transportation-controlled environments may also be important. In another embodiment, exposure to light may be important. All of these can be readily incorporated in the system described simply by changing or adding sensor components to the label. For example, shock loads can be calculated by adding a three-dimensional accelerometer to the PCB assembly such as a Micro-Electro-Mechanical Systems (MEMS) based device. Thus, it is clear that the device could contain multiple sensors of the same or different types.

Such accelerometer devices are widely used in smart devices and are thus manufactured in very high volumes and are available at low cost, use very low power and are thus suitable for incorporation into a label assembly including a small battery with low capacity. Unfortunately, such devices although they can withstand high shock loads such as might be experienced by a package being dropped when it impacts a hard surface, because of the very small size of the microstructure within the integrated circuit, can usually only measure gravitational force changes of the order of magnitude of between Og to 20g. This is much less than might be an acceptable limit for reasonable handling of goods in a transportation chain. Impact limits for acceptable handling might for example be as high as an order of magnitude higher than this. Similar, higher cost accelerometer devices with larger internal microstructures are available which can measure higher levels of deceleration but these can only usually

monitor at lower frequencies and utilise significantly higher power levels which make their use in the proposed small label format with limited battery capacity unsuitable. The more sensitive devices can however detect successfully a free fall condition of a package to which the label and thus the sensor are attached. Detection of this condition can be utilised to estimate the height from which a package or item has been dropped and combined with the subsequent profile of the measurements from the accelerometer these can be used to determine if an exceedance of reasonable handling has occurred and an alarm indication such as the flashing of the LED on the label instigated. Fig 8 illustrates the impact characteristics of such a sensor with a maximum measurement range of only 16g which has been subjected to a deceleration force of 100g. Additionally, the identification of a free fall condition can be used by the microprocessor to increase the frequency of monitoring of the accelerometer device to more effectively capture the impact characteristics when the package is decelerated. In this way, handling of such as a package being thrown from one operator to another during the loading of a vehicle can be distinguished from a free fall onto a hard surface which it may have damaged the goods or package. More frequent monitoring of acceleration by the accelerometer consumes more power and so the detection of a free fall event as a trigger to increasing monitoring frequency is important to extend the battery life of the label. It is obvious that a PCB assembly with both the smaller more sensitive accelerometer to identify a free fall condition and the higher cost device could be used to measure directly the impact force level which would trigger an exceedance where the smaller device was used to identify to the microprocessor to turn on the larger more power hungry device and thus reduce the average power consumption level required for monitoring and measurement.

It will be obvious that if the PCB assembly on which the accelerometer device or devices are mounted is to estimate or directly measure the impact force during rough handling that the PCB assembly must be mounted in the label assembly in such a manner that the PCB assembly experiences the same forces as the package when impact occurs.

It is also an objective that the PCB assembly of the tag can be re-used. The construction is such that the PCB assembly can be readily removed from the tag enabling the preform and the printed cover to be recycled and the PCB returned to the factory where a new battery is installed, the electronic memory cleared and the microprocessor enabled to be utilised once again in the production process. As the effective housing of the tag is completely replaced any damage during transportation is not visible and a re-used tag is indistinguishable from a newly constructed one, which would not be the case if the assembly used a traditional rigid housing. In this manner the effective cost of the tag is reduced and the most environmentally friendly use of shipment monitoring electronics for goods and packages in a transportation system is achieved.

The default operation of the software programme running on the label's microcontroller when first powered up is to check at a specific location for a specific value. If an unrecognised specific value is detected then it indicates that the label has just been manufactured or is corrupted. The label then enters a "production" mode whereby it can be configured through the radio interface in the factory, that configuration being written to the non-volatile memory along with a specific value being written to the specific location to record the progression from "production" to "shelf" mode indicating that when the programme is next started and the "shelf" mode specific value is retrieved from the specific location, the ability to set factory configuration options is removed and logging is started. Once logging is started, a different specific value is written to the specific location indicating that the label is in "logging" mode. When a label is recycled at the manufacturing facility, the cells are replaced and fresh cells inserted. When the microprocessor is powered up, the specific value read from the specific location will indicate that the label is in "logging" mode which means that it is being recycled. As such the programme erases all data from the non-volatile memory and then enters "production" mode again ready to be reconfigured and subsequently set back into "shelf" mode.

A further preferred feature of the system is that it should be easy to use and have a low barrier to entry. To this end, it is beneficial to dispense with user authentication to

access remote resources such as the cloud data storage facility. To dispense with authentication altogether however would be a poor design decision and potentially risk contravention of regional statutes and therefore an alternative mechanism is implemented within the present invention. The integrity of the recorded data is paramount if it is to be trusted and so when the data is retrieved by the smart device application from the tag, each part is passed through a checksumming algorithm which may be a well known published one such as, but not limited to, a cyclic redundancy check, Fletcher's checksum or Adler-32 or alternatively a proprietary algorithm. Once all logged environmental data has been passed to the application, then the plain checksum is also passed along with a cryptographic hash of the checksum made with a pre-shared key that was randomly generated and written to the tag at time of manufacture and is known only to both the tag and the server, The complete data set can then be checksummed by the application and compared against the plain checksum to verify that all data has been retrieved before the complete data set is sent up to the server along with the cryptographically hashed checksum. Once retrieved at the server, the complete data set is checksummed using the same checksumming algorithm used by the tag. This server calculated checksum is then also cryptographically hashed using the same algorithm and pre-shared key that was assigned to the tag and the hashes compared. If the hashes match then the data is accepted into the cloud based system and stored but if they do not match then it could indicate that either the logged data was incompletely transferred up to the server, that logged data was deliberately or accidentally altered by a system such as a malicious application at some point between the tag and the server or that the data was entirely fabricated and never came from that specific tag. In any of these failure cases, a response is sent to the application indicating that the data was not accepted by the system which may cause a further attempt to retrieve all of the data from the tag again.

The applicant hereby discloses in isolation each individual feature described herein and any combination of two or more such features, to the extent that such features or combinations are capable of being carried out based on the present specification as a whole in the light of the common general knowledge of a person skilled in the art, irrespective of whether such features or combinations of features solve any problems

disclosed herein, and without limitation to the scope of the claims. The applicant indicates that aspects of the present invention may consist of any such individual feature or combination of features. In view of the foregoing description it will be evident to a person skilled in the art that various modifications may be made within the scope of the invention.

CLAIMS

1. A sensing device for monitoring a condition of an item, the device comprising:

a sensor for detecting one or more specified conditions associated with the item being monitored;

a memory for receiving data from the sensor and recording at least some of the data associated with one or more of the specified conditions of the item, wherein the data to be recorded includes data about one or more alarm conditions which occur when a specified condition passes outside a specified threshold range; and

a housing for retaining the sensor and the circuit, the housing being configured to be mounted to the item being monitored, further comprising

a data output device for receiving data about the specified condition(s) and outputting that data to a remote device.

2. A sensing device according to claim 1, wherein the sensor and the circuit are mounted on a common structure such as a PCB.

3. A sensing device according to claim 2, wherein the common structure is readily removable from the housing to allow reuse of one or both of the common structure and the housing.

4. A sensing device according to any of the preceding claims, further comprising a tracker for identifying the actual location of any alarm condition.

5. A sensing device according to claim 4, wherein the tracking is done by one or more of GPS, cellular triangulation or NB-IoT.

6. A sensing device according to any of the preceding claims, further comprising a momentary switch for controlling the activation of the sensor.

7. A sensing device according to any of the preceding claims, further comprising a microprocessor.

8. A sensing device according to any one of the preceding claims, wherein the data output device is one or more of an outlet port or a wireless communication device.

9. A sensing device according to claim 8, wherein the wireless communication device is one of RFID, Bluetooth, wi-fi, radio or other near field communication device.

10. A sensing device according to any one of the preceding claims, wherein the housing includes a rigid shell.

11. A sensing device according to any one of the preceding claims, wherein the housing includes an adhesive strip.

12. A sensing device according to any one of the preceding claims, further comprising one or more batteries, wherein at least one of the batteries is located and sized to provide structural resistance to protect the circuit during crushing of the housing towards the item.

13. A sensing device according to claim 12 wherein at least one of the batteries is the tallest component within the housing.

14. A sensing device according to any one of the preceding claims, wherein the circuit only records data when a predetermined threshold associated with the condition has been reached.

15. A sensing device according to any one of the preceding claims, wherein the data recorded includes a time stamp to indicate when the threshold is reached.

16. A sensing device according to claim 14 or claim 15 wherein the memory records only the first occurrence of the threshold being reached.

17. A sensing device according to claim 14 or claim 15, wherein the memory records multiple occurrences of the threshold being reached.

18. A sensing device according to any one the preceding claims, wherein the housing has a hinged section for use in retaining the sensor and/or memory circuit.

19. A sensing device according to any one of the preceding claims, further comprising an alarm for providing a visible indication to a user of an alarm condition having been triggered.

20. A sensing device according to claim 19, wherein the alarm includes an LED.

21. A sensing device according to any one of the preceding claims, further comprising an integrated circuit for controlling the device.

22. A sensing device according to any one of the preceding claims, wherein the memory is non-volatile.

23. A sensing device according to any one of the preceding claims, the memory is volatile.

24. A system for monitoring the condition of an item, the system comprising a sensing device according to any one of the preceding claims, and a smart device application, the application being capable of communicating with the device to obtain the recorded data.

25. A method of monitoring the condition of an item using a device according to any one of the preceding claims, the method comprising:

interrogating the memory of the sensor device to obtain data associated with the condition of an item to which the device has been attached by using an application loaded onto a smart device; and

communicating with a remote system using the application to record the condition of the item.

26. A sensing device according to claim 1, wherein the housing includes two hollow recesses separated by a rib.

27. A sensing device according to claim 26, wherein one of the recesses encloses a PCB on which the electronic components of sensing device are mounted.

28. A sensing device according to claim 27, wherein the rib is sized such that it prevents accidental contact with any of the electronic components on the PCB.

29. A sensing device according to any of claims 27 or 28, wherein the rib is taller than the uppermost electronic component.

30. A sensing device according to any of claims 27 to 29, wherein the rib is taller than any switch on the PCB.

31. A sensing device according to any of claims 26 to 30, wherein the recess in which the PCB is located includes one or more internal projections for limiting the movement of any battery mounted on the PCB.

32. A method according to claim 25, further comprising the step of, after initial configuration of the device, setting the sensor device to a low power mode in which condition information about the location of the sensor is recorded at a significantly reduced rate compared to normal operation.

33. A method according to claims 32, wherein the reduced rate is approximately once per hour.

34. A method according to claim 33, wherein, upon full activation of the device, the low power mode data is deleted.

35. A method according to any of claims 25 and 32 to 34, further comprising the step of, during configuration of the sensor, setting a delay to the activation of any alarm.

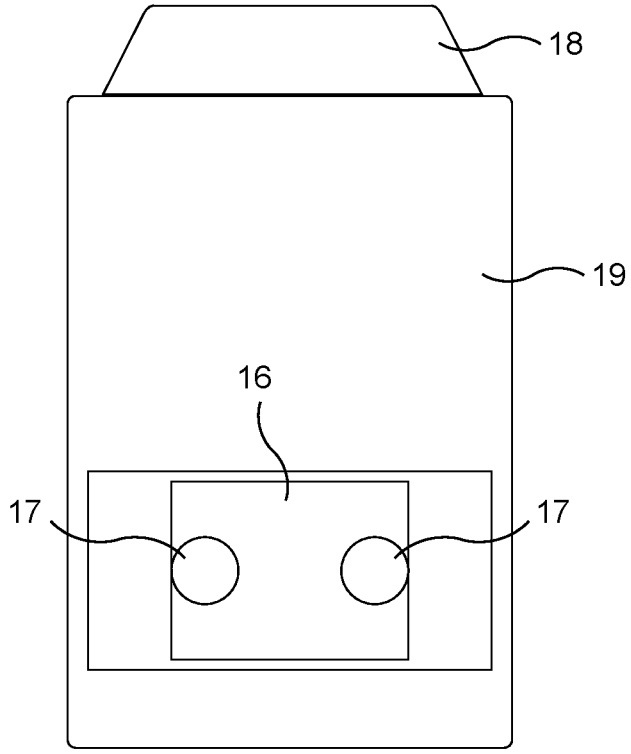
36. A method according to claim 35, wherein the delay is until the sensor first reaches the acceptable range of the condition which is to be monitored.

37. A method according to claim 36, wherein the delay is set to a maximum period time such that, upon reaching this maximum time period, any alarm is placed in normal operation regardless of the acceptable range.

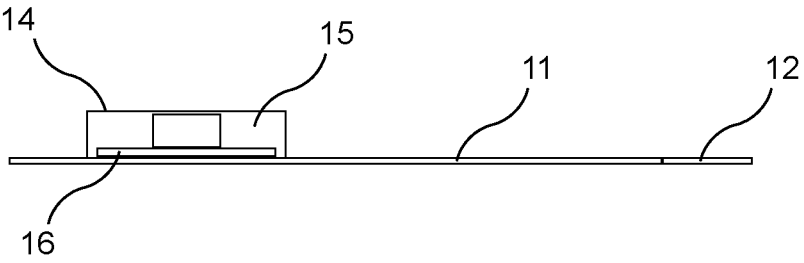
38. A method according to any of claims 25 and 32 to 37, further comprising the step of, during configuration, setting an alarm on the device such that the alarm is triggered only if a threshold condition is exceeded for a predetermined period of time.

Figure 1

(a)



(b)



(c)

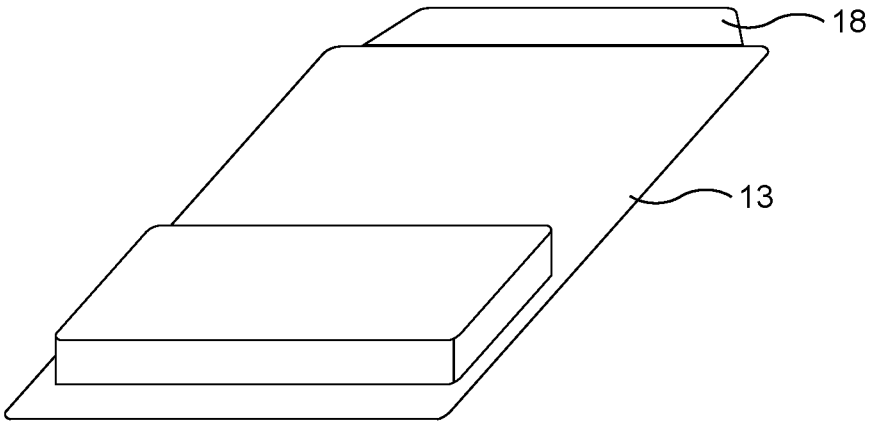
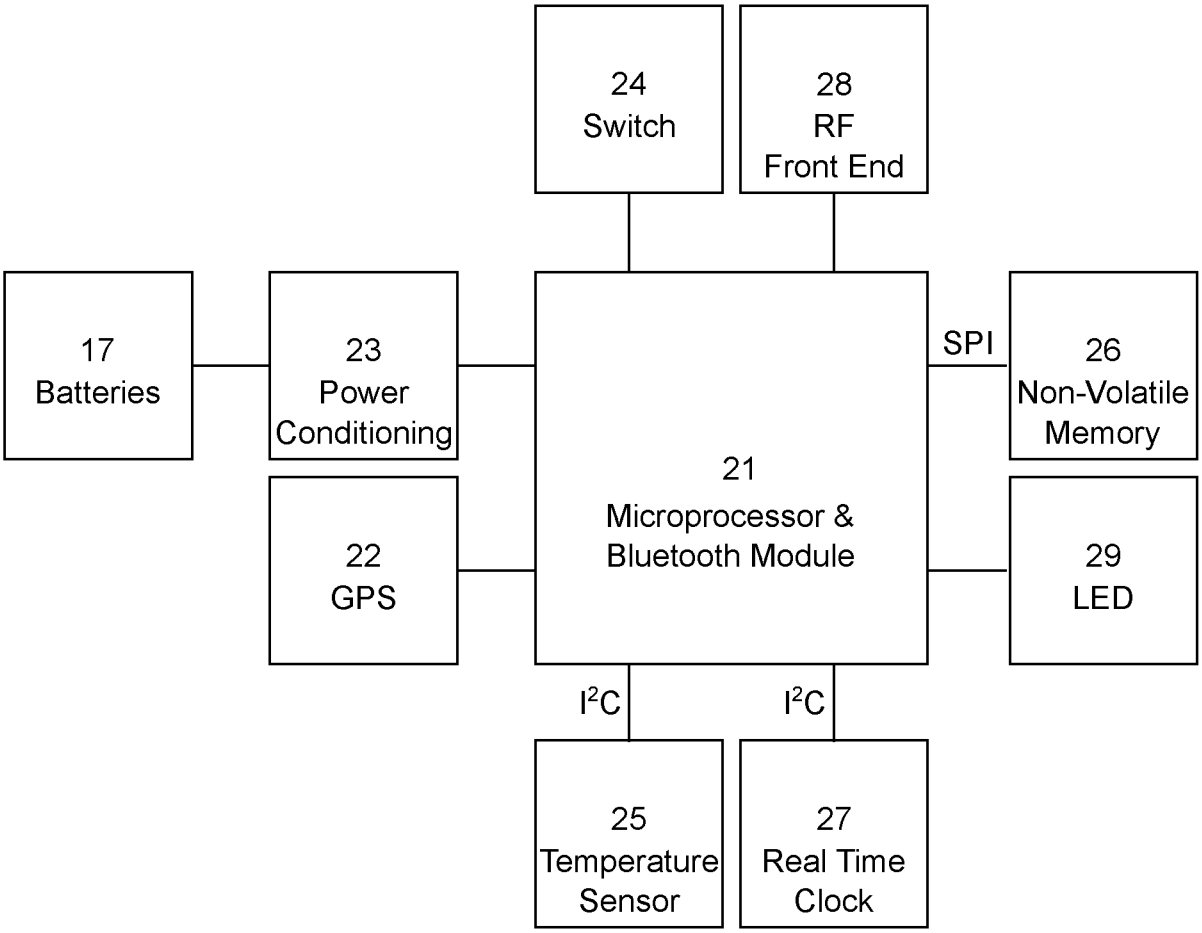


Figure 2


24
Switch
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RF
Front End
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Batteries
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Power
Conditioning
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Microprocessor &
Bluetooth Module
SPI
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Non-Volatile
Memory
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GPS
29
LED
I2C
I2C
25
Temperature
Sensor
27
Real Time
Clock

Figure 3

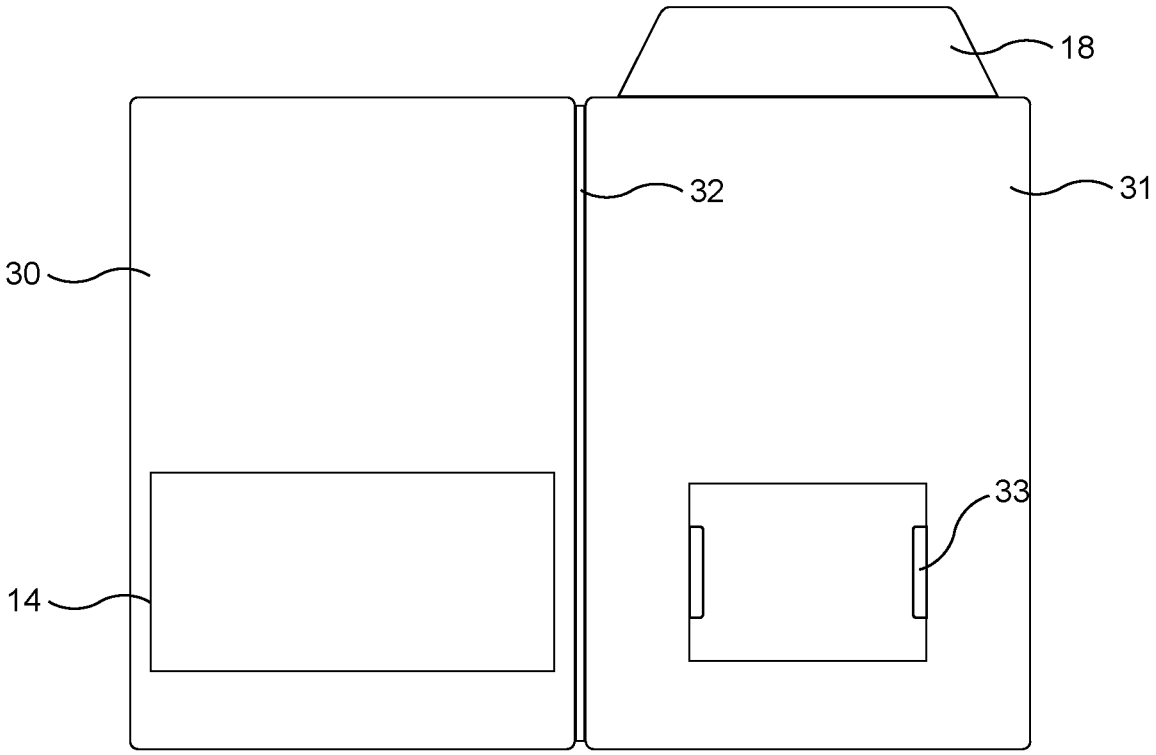


Figure 4

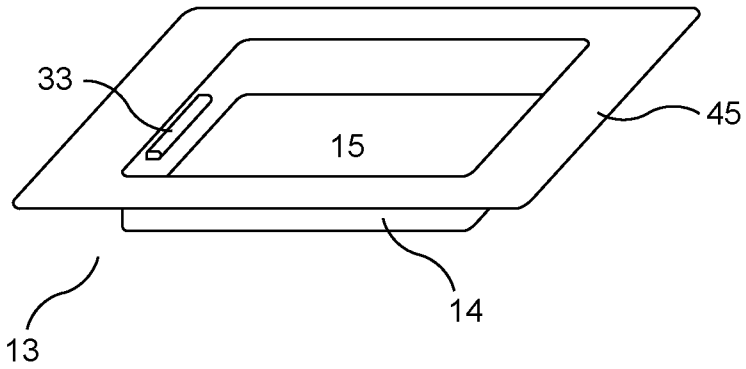


Figure 5

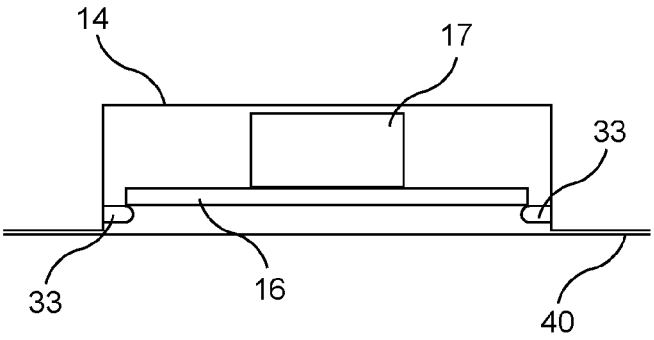


Figure 6

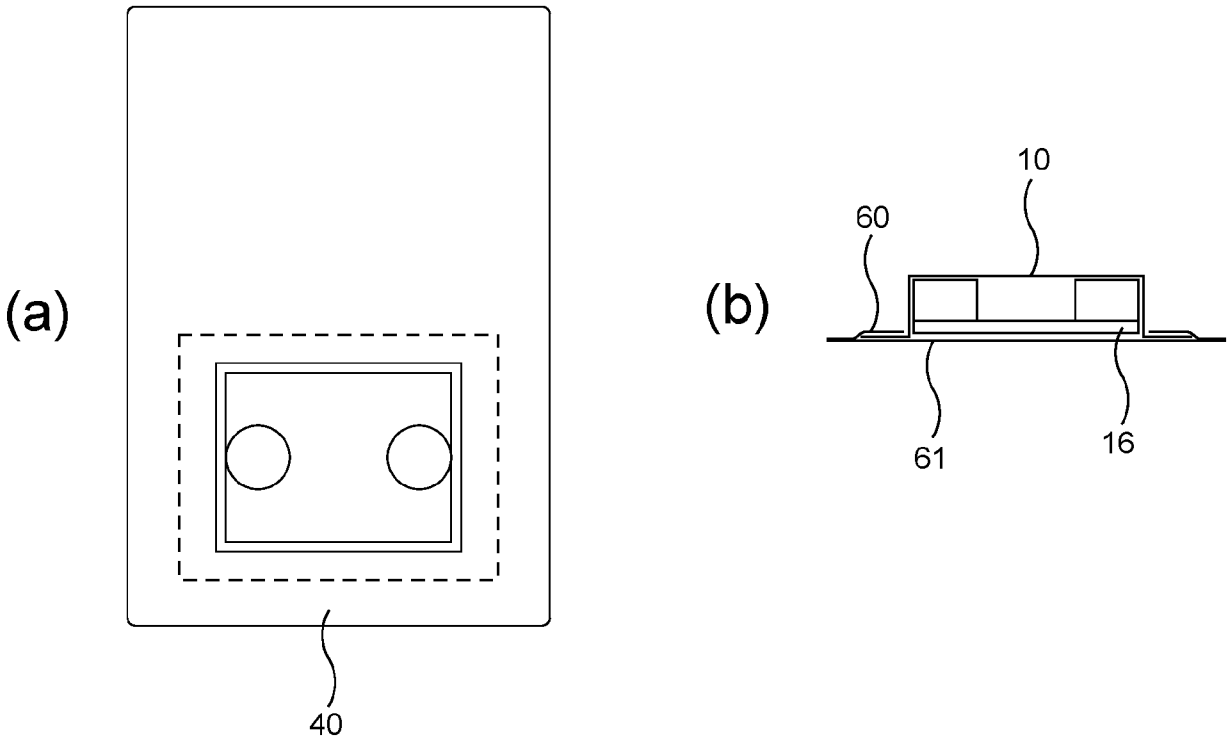


Figure 7

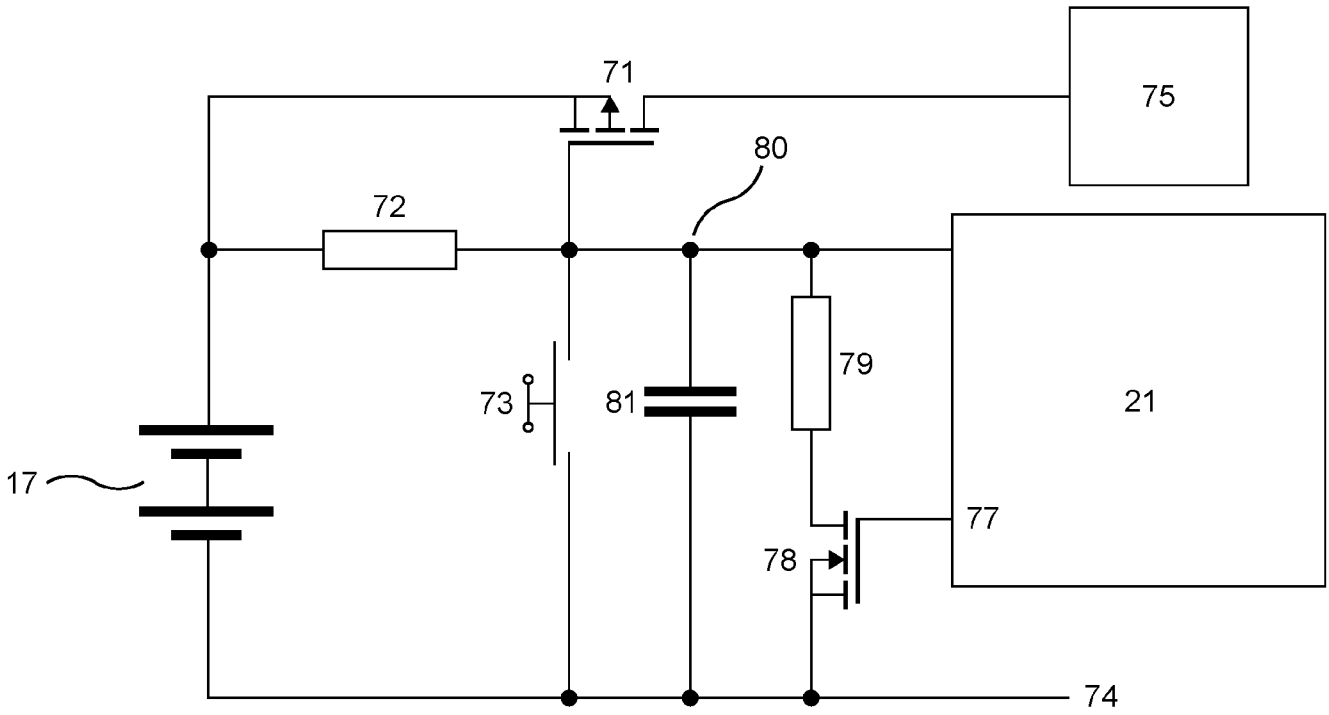


Figure 8

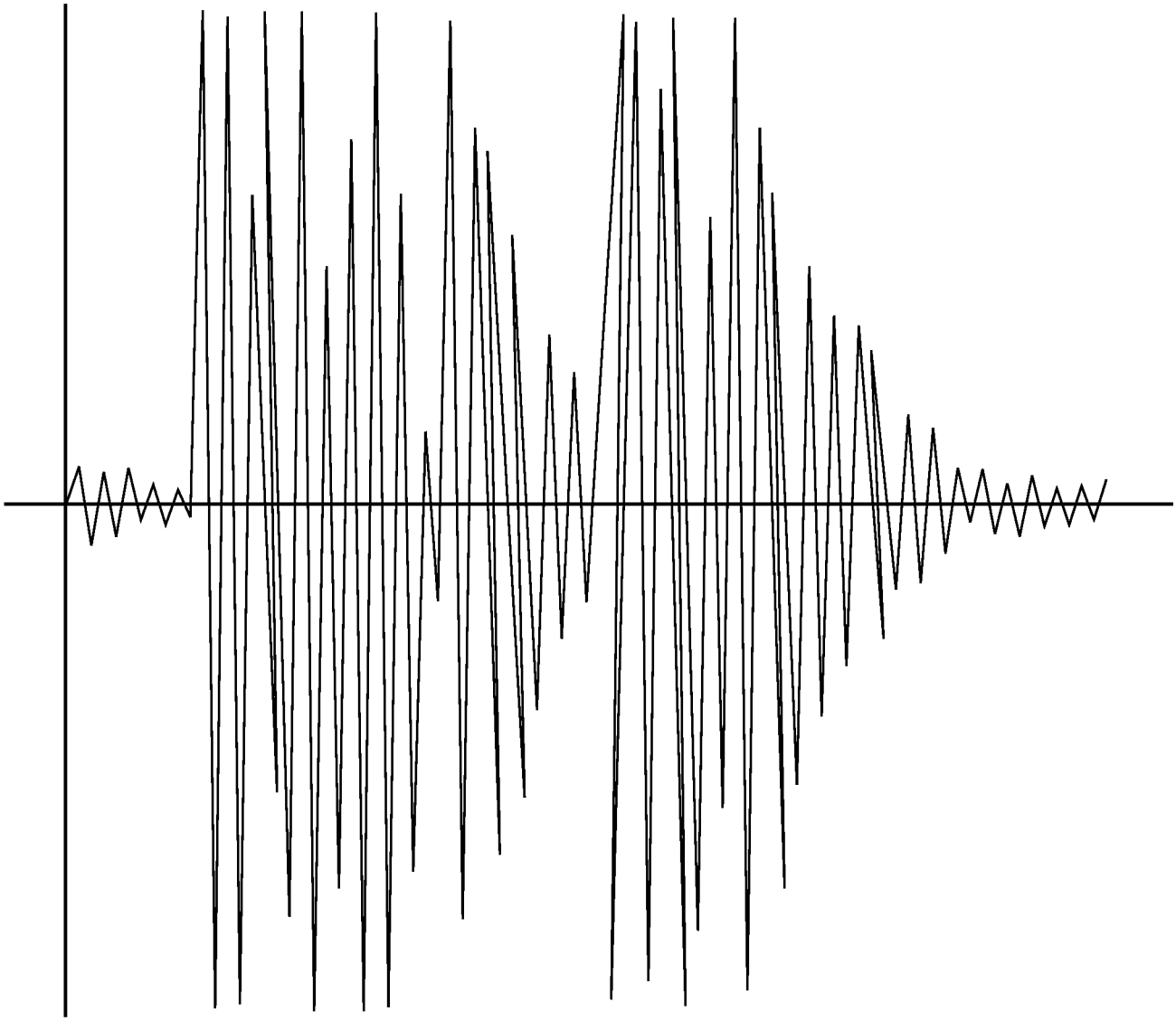
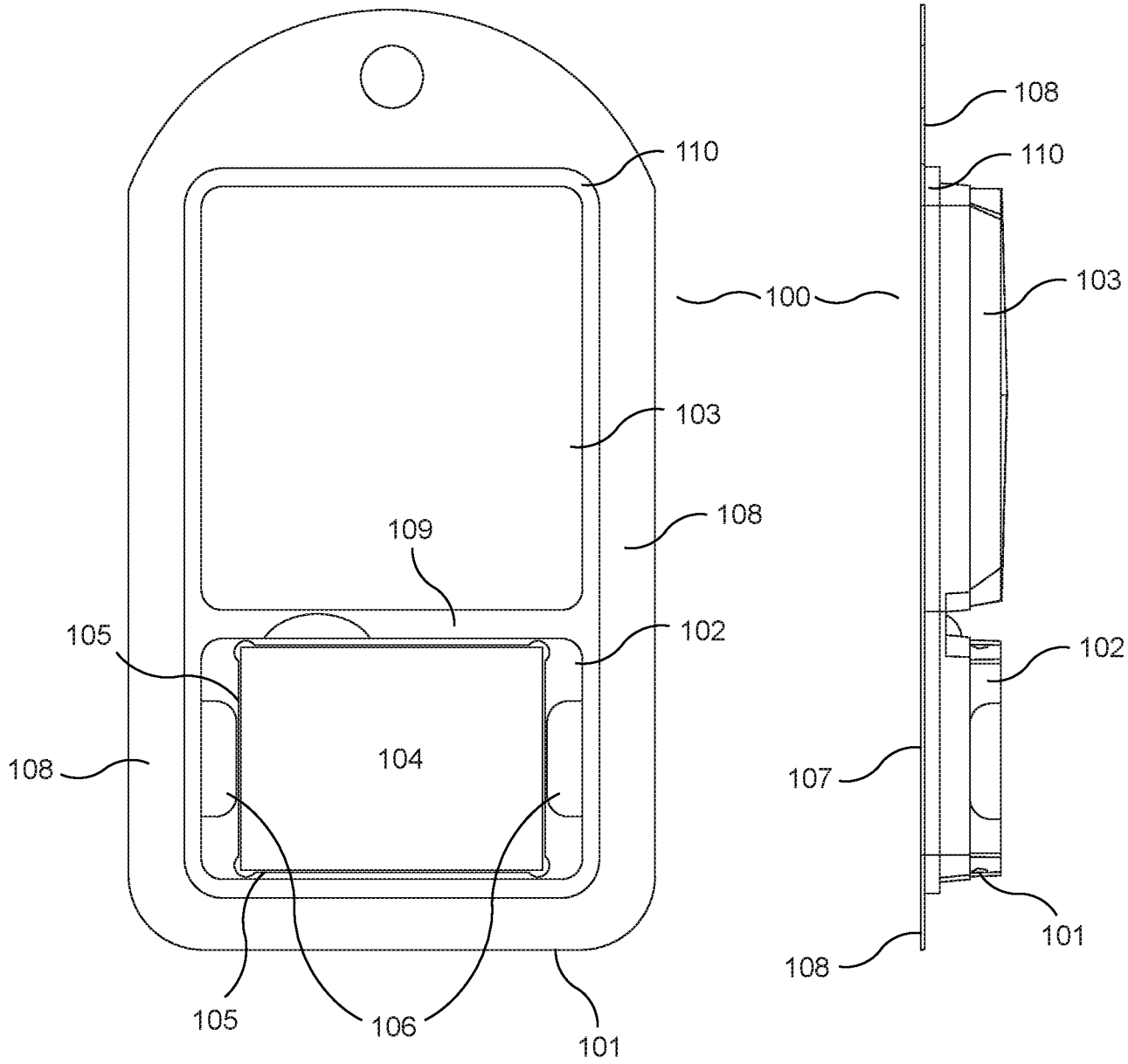


Figure 9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INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2019/051904

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01D9/00 G01K1/02 G01K3/00
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)
G01D G01K

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)
EPO-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 2015/382085 A1 (LAWRIE-FUSSEY THOMAS [GB] ET AL) 31 December 2015 (2015-12-31) abstract; figures paragraphs [0002], [0025] - [0039]	1-38
A	US 2007/255163 A1 (PRINEPPI FRANK J [BS]) 1 November 2007 (2007-11-01) abstract; figures 1-4 paragraphs [0016] - [0032]	1-38
A	US 9 767 656 B2 (PAKSENSE INC [US]) 19 September 2017 (2017-09-19) abstract; figures 1-4 column 6, lines 48-67 column 10, lines 54-65 column 17, lines 34-50	1-38

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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Date of the actual completion of the international search	Date of mailing of the international search report
24 September 2019	11/10/2019

Name and mailing address of the ISA/	Authorized officer
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