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(54) **PUMP SYSTEM MODULAR COMPONENTS FOR DELIVERING MEDICATION AND ANALYTE SENSING AT SEPERATE INSERTION SITES**

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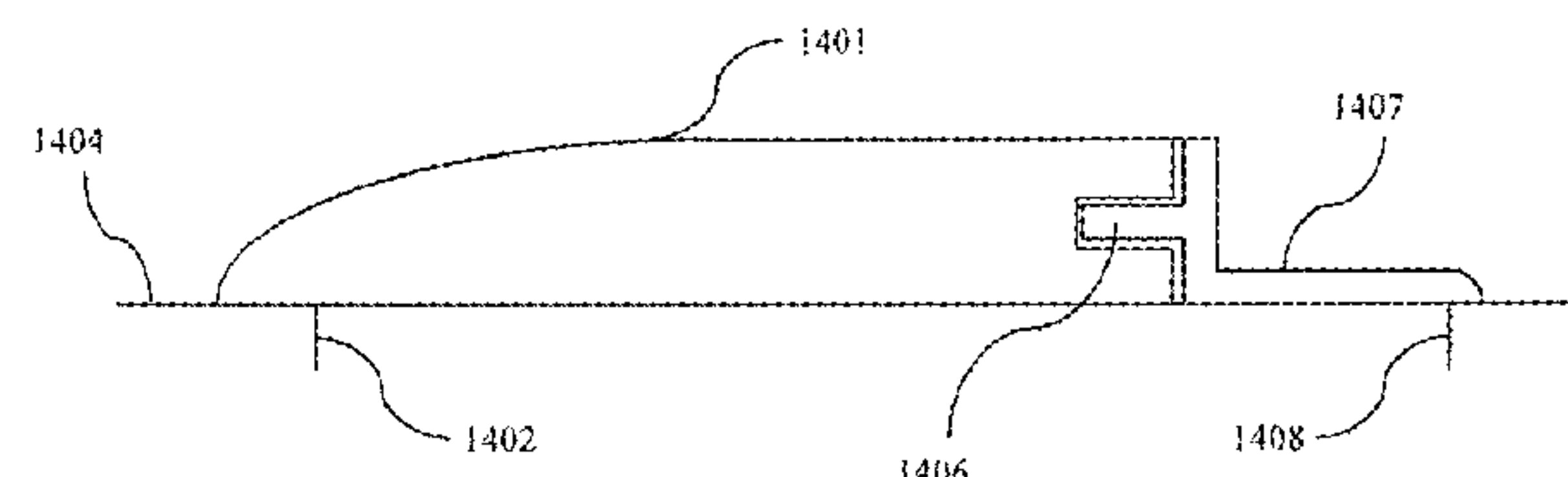
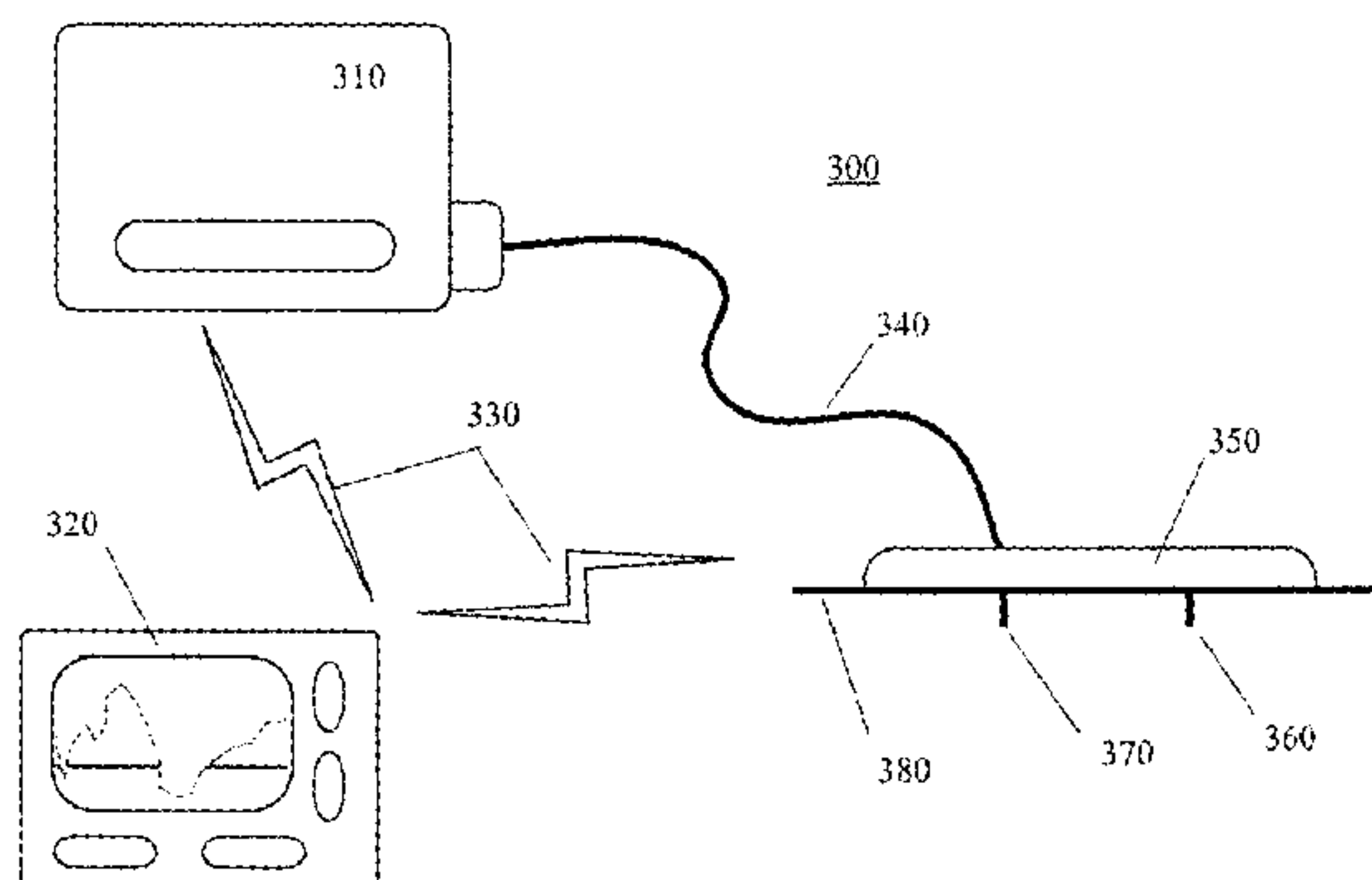
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(57) **ABSTRACT**

Methods and systems for providing modular components in an integrated infusion device and analyte monitoring system where the components are independently replaceable are provided.

**20 Claims, 11 Drawing Sheets**



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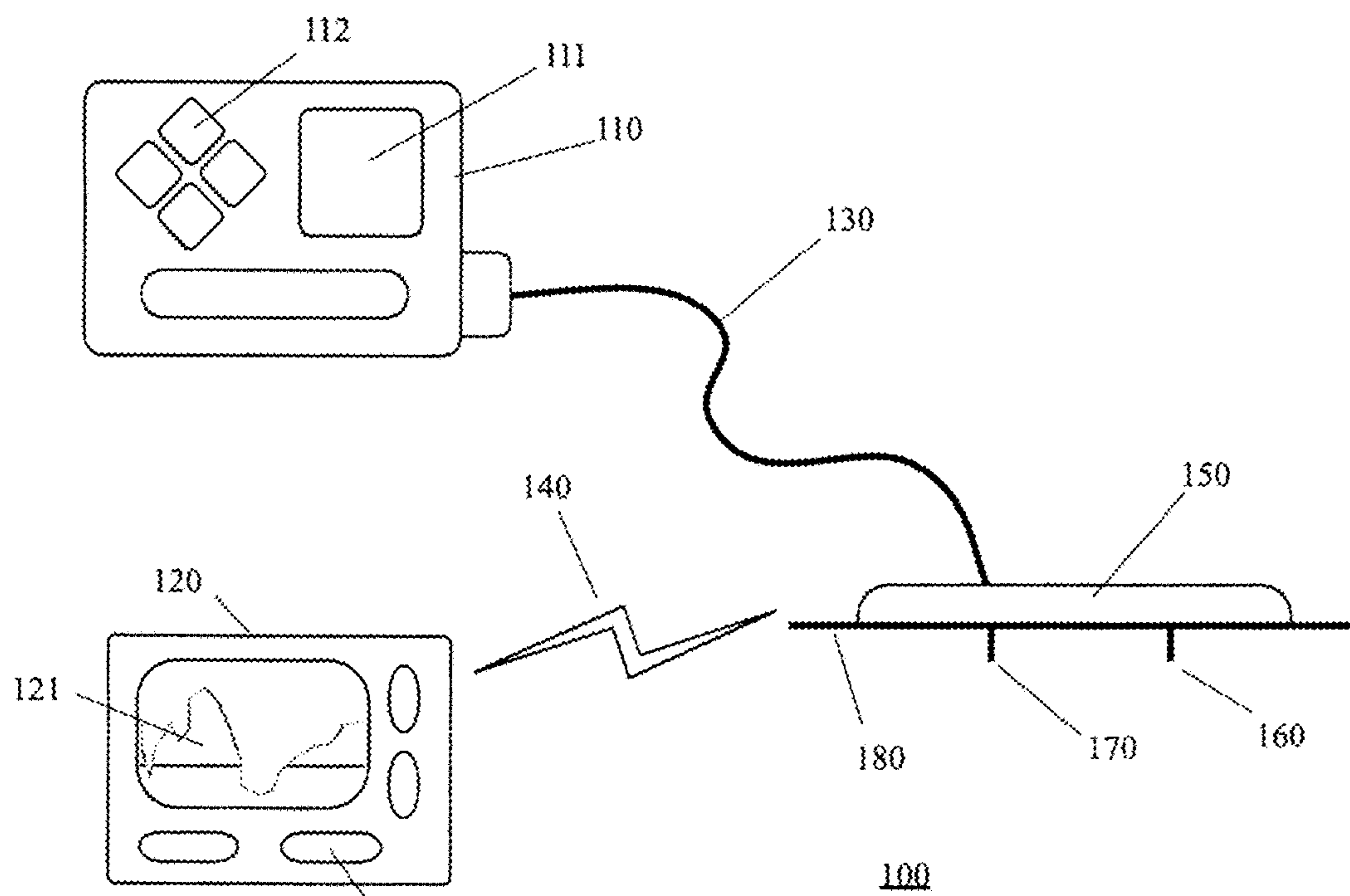


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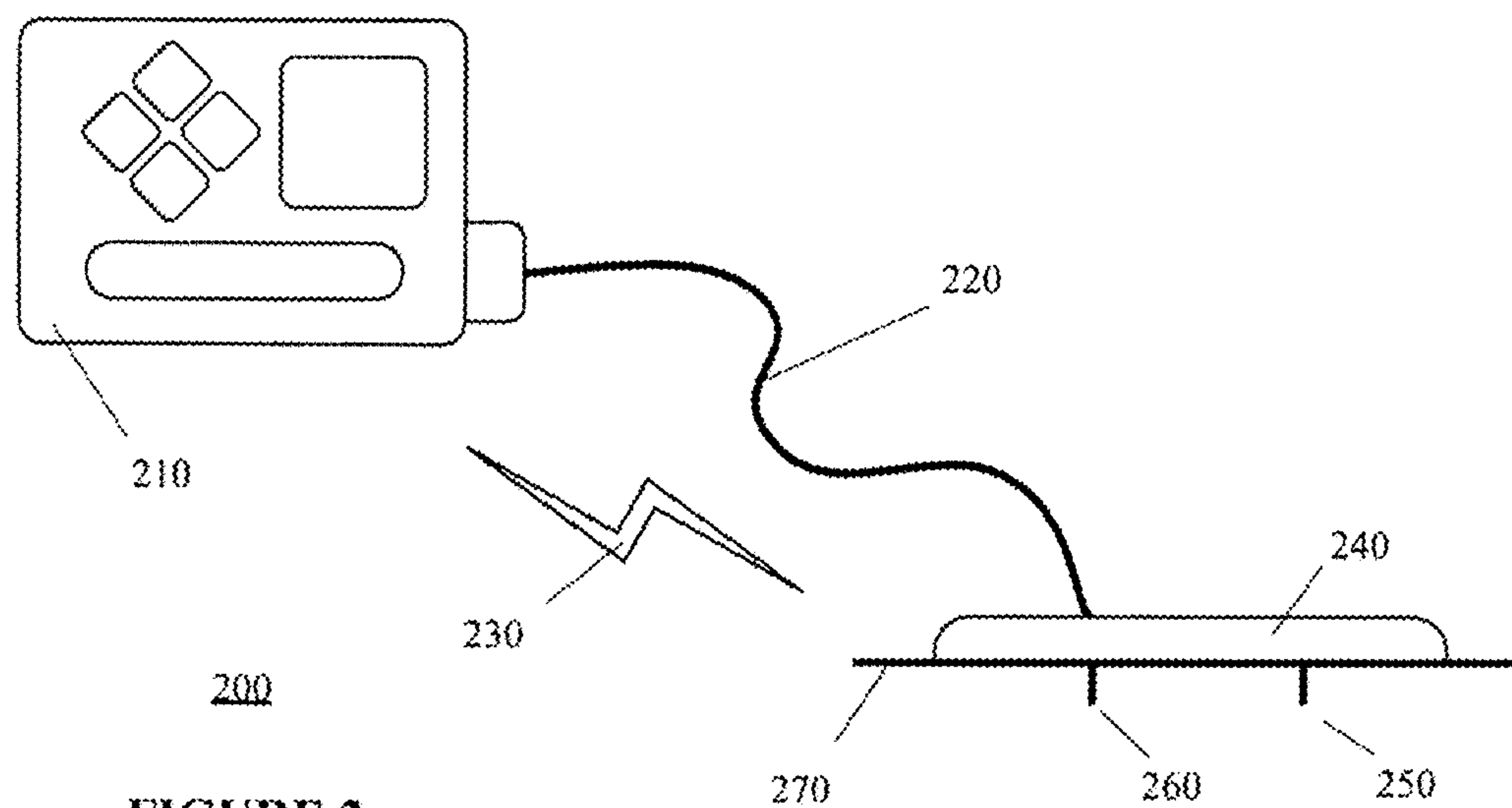
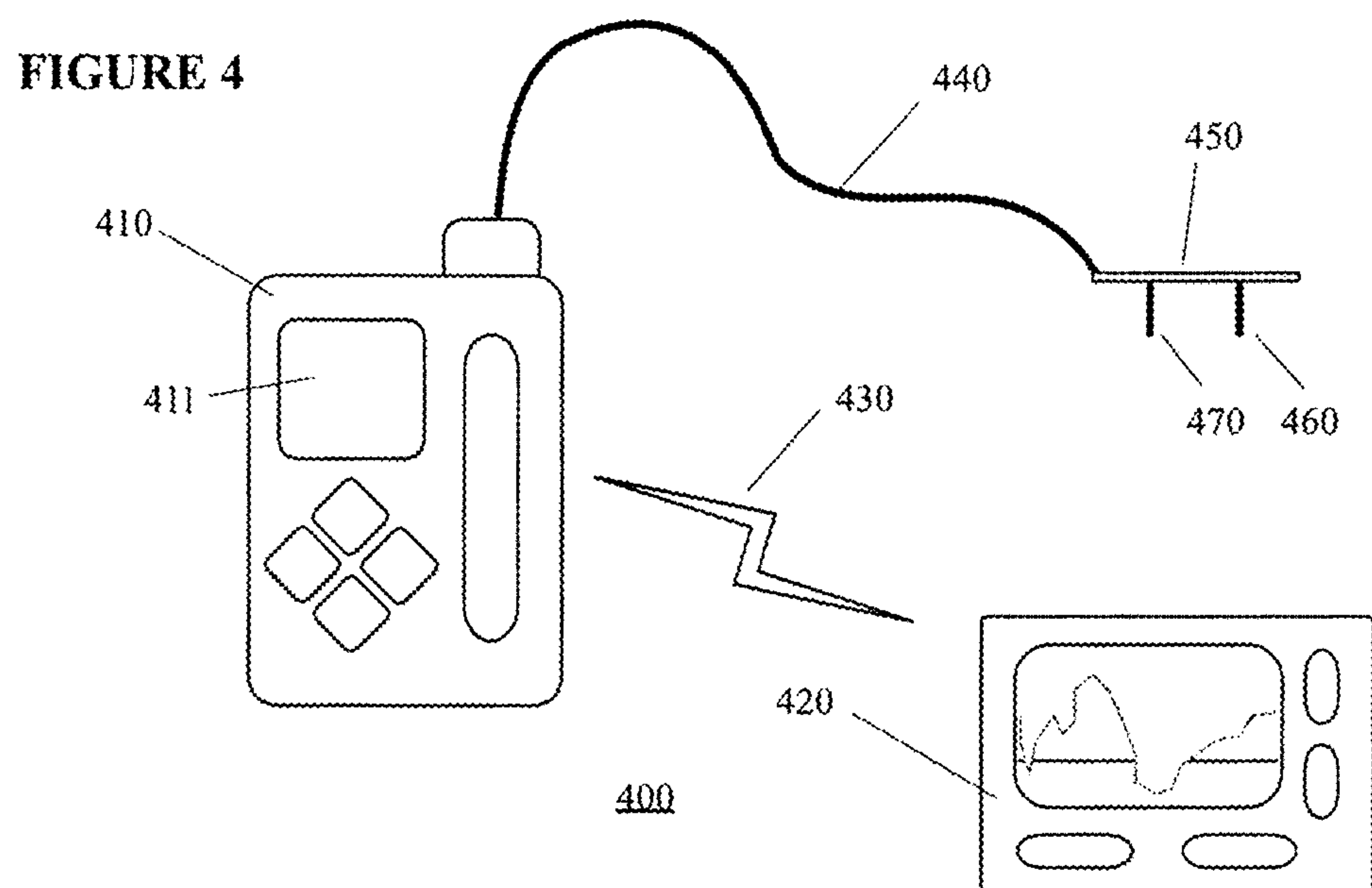
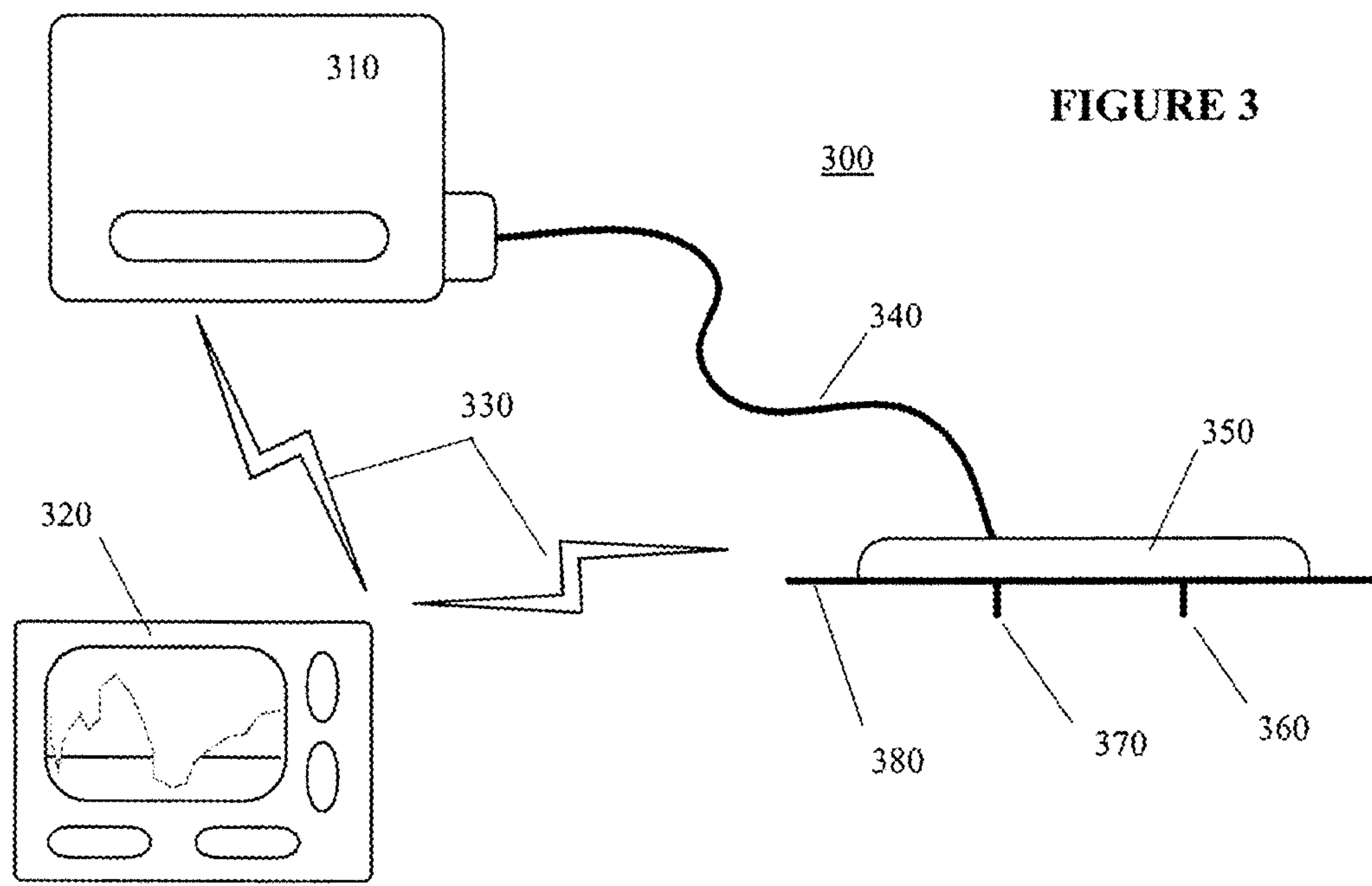


FIGURE 2







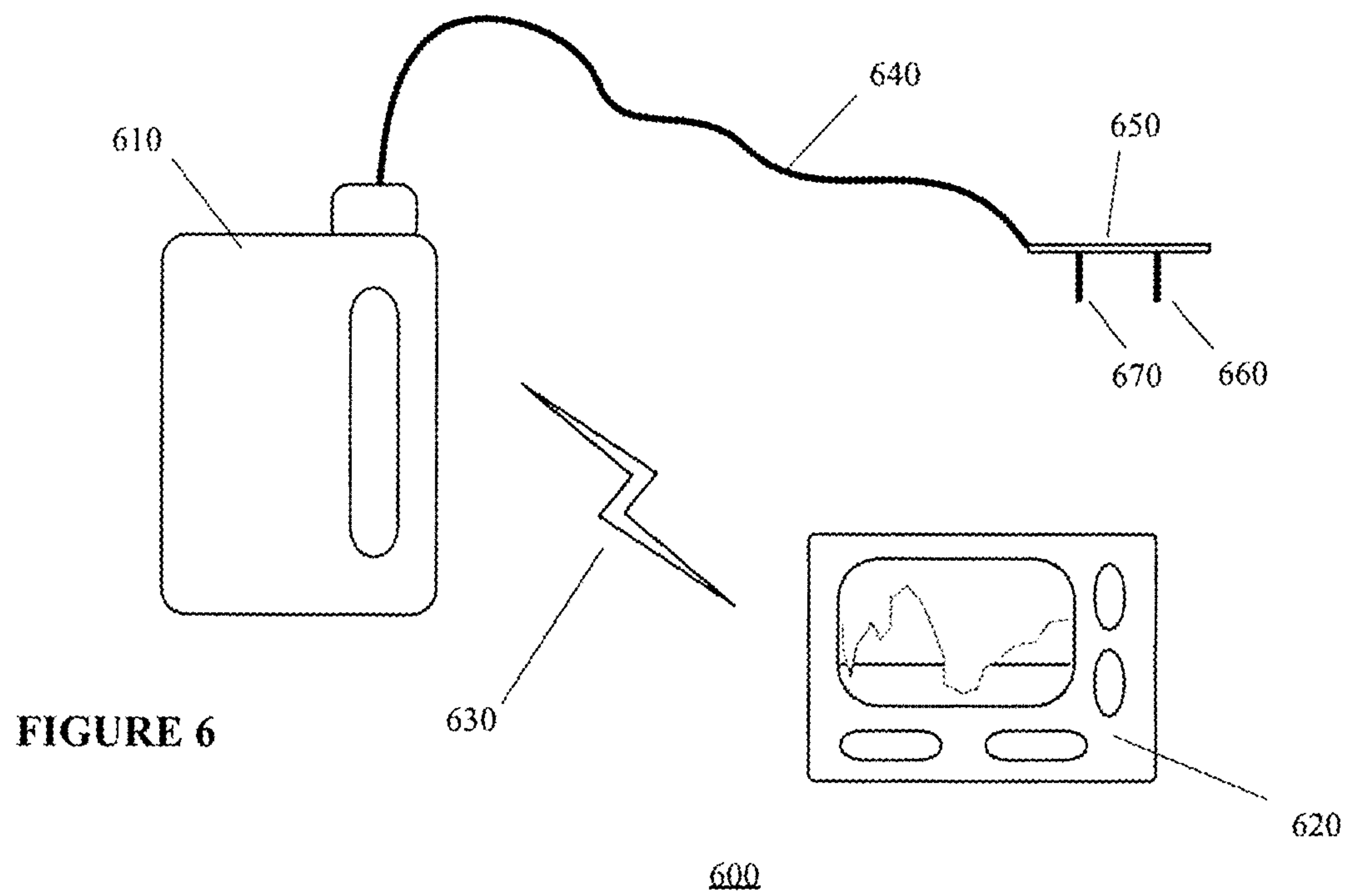
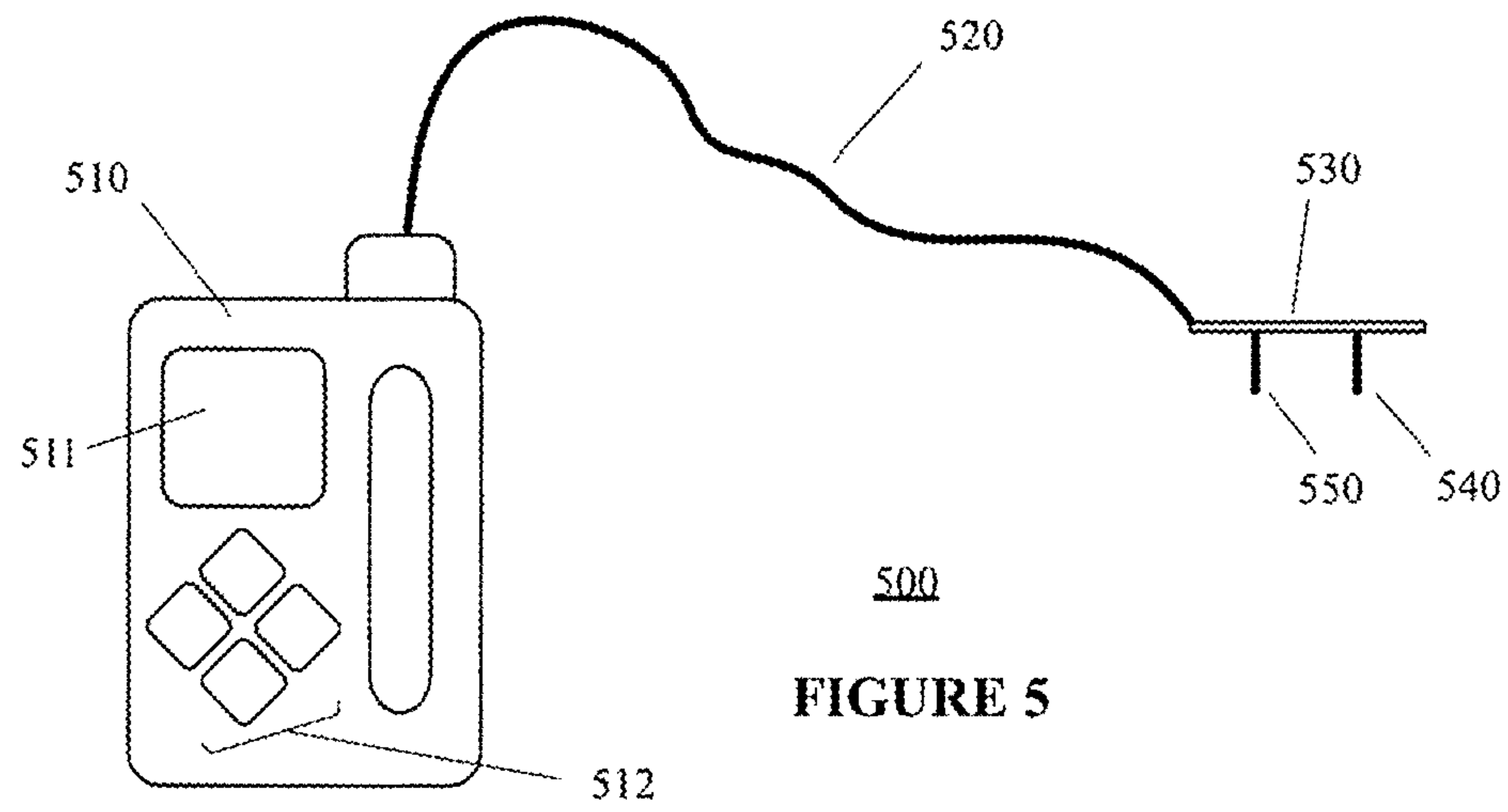




FIGURE 7A

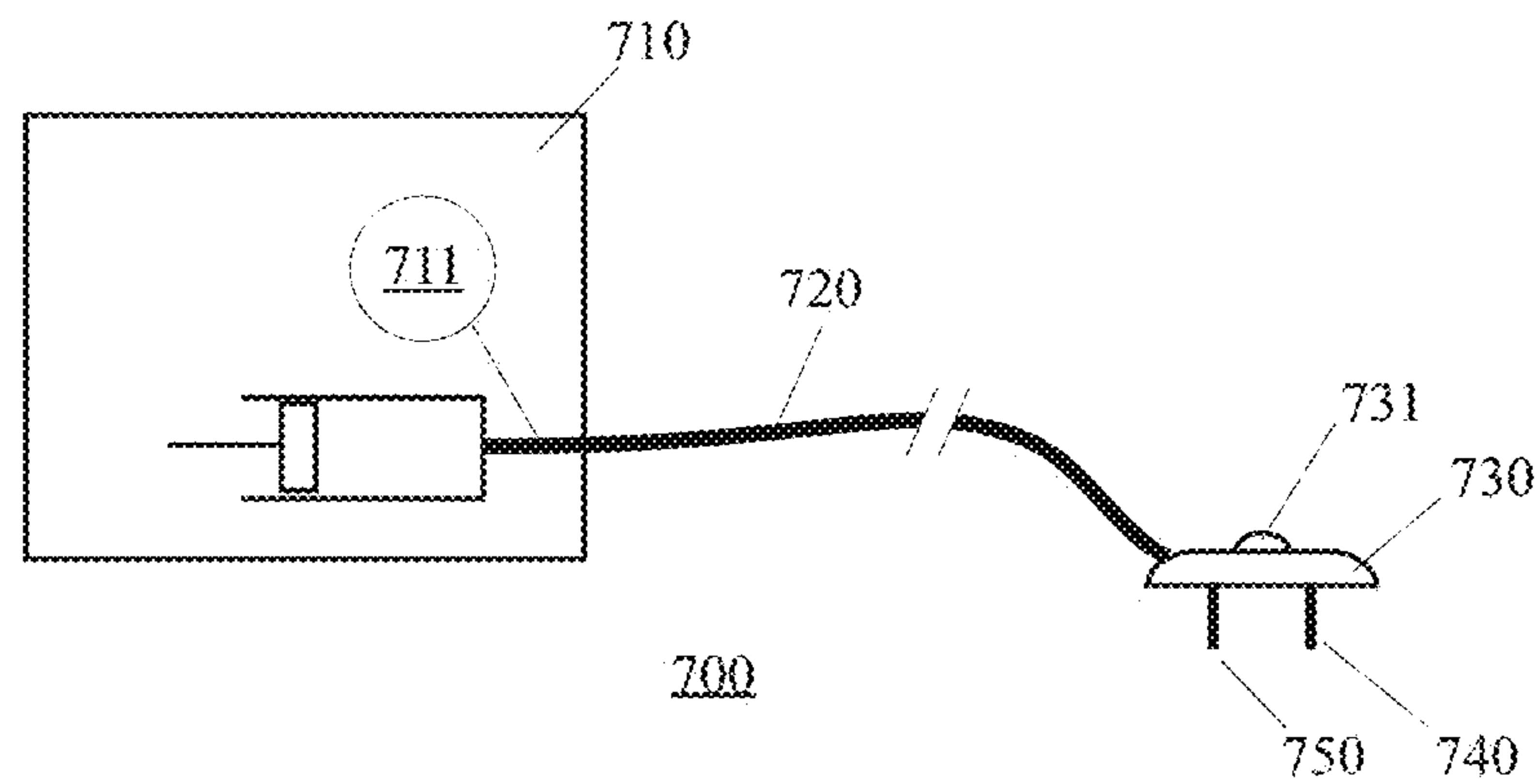


FIGURE 7B

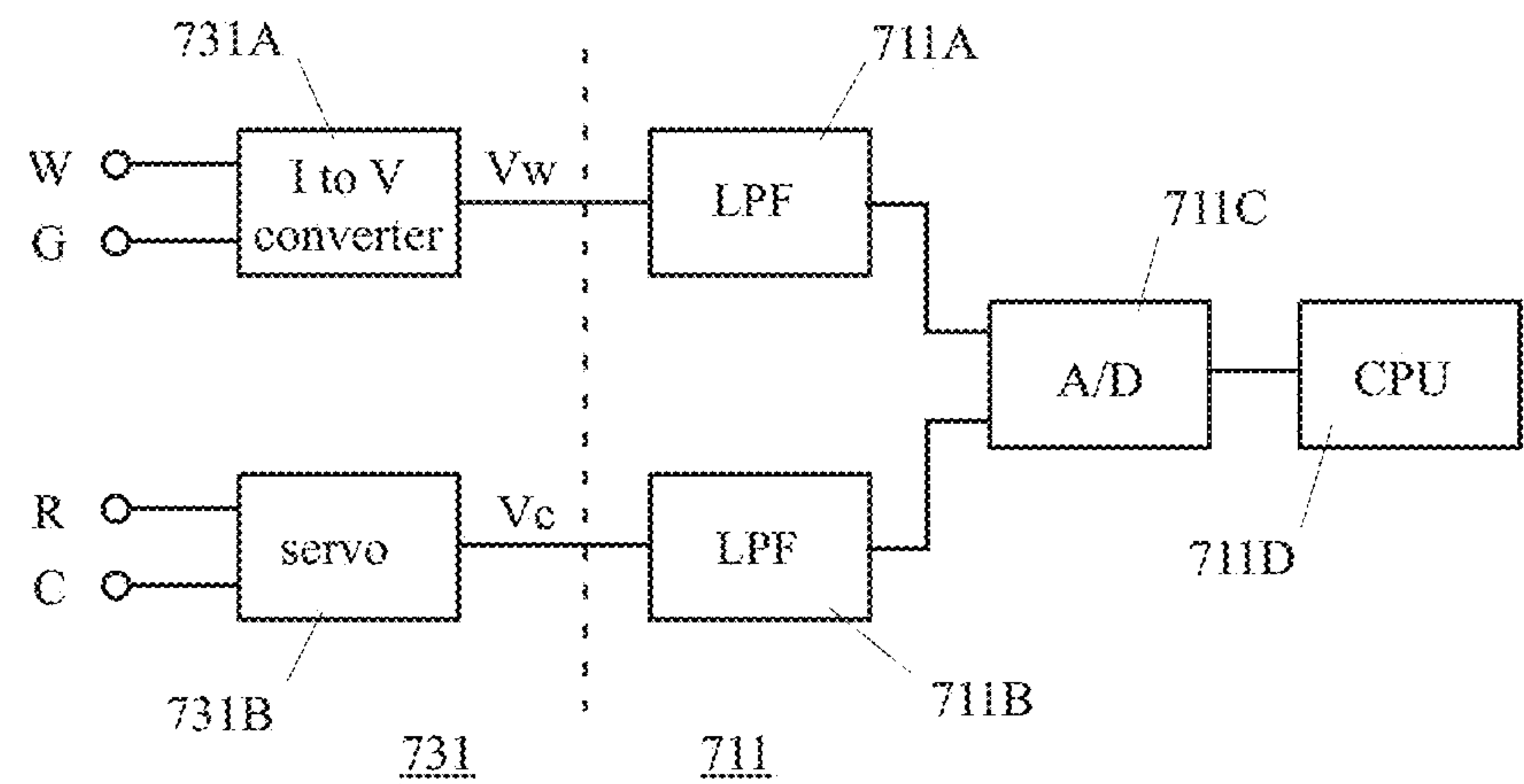
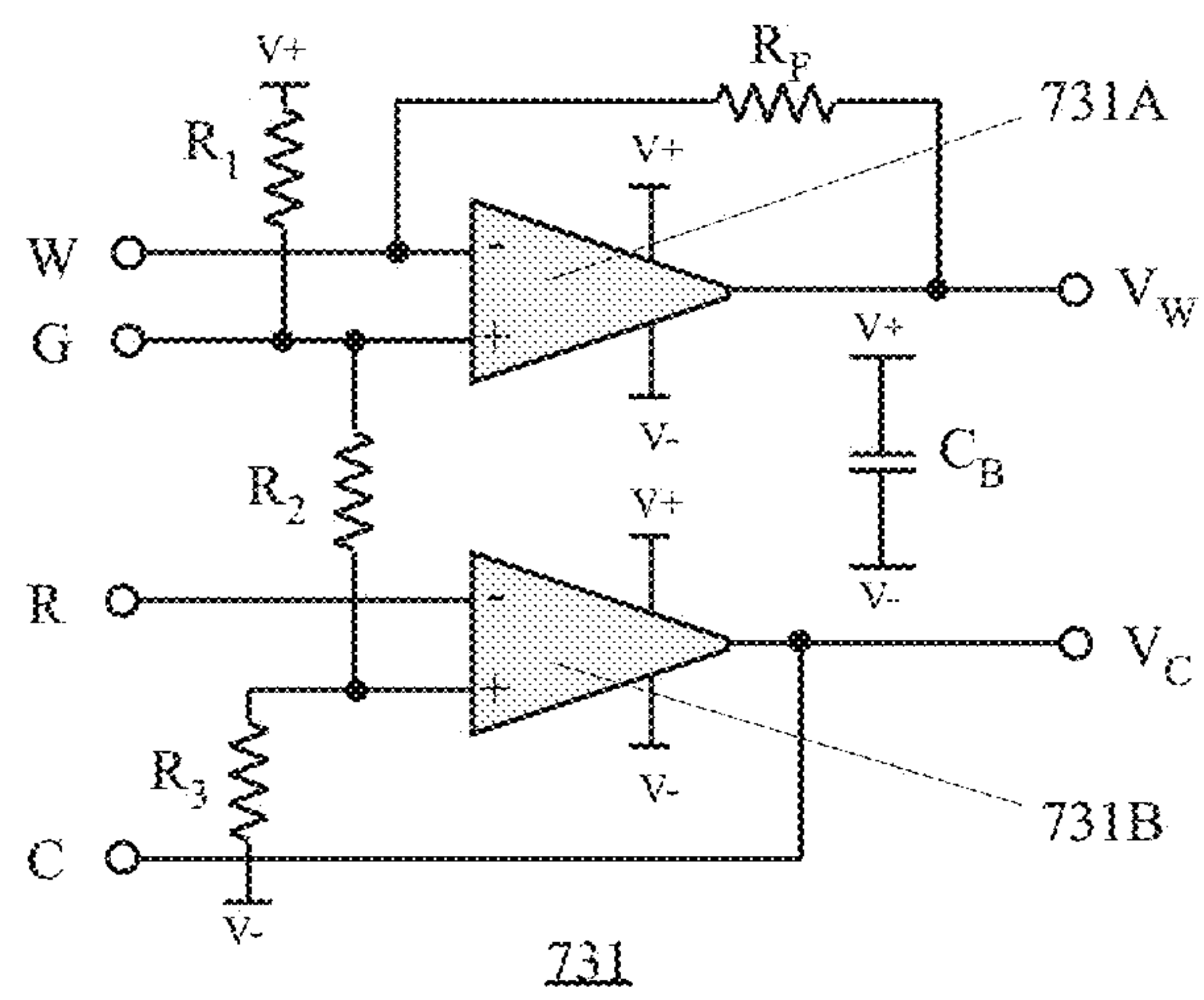


FIGURE 7C



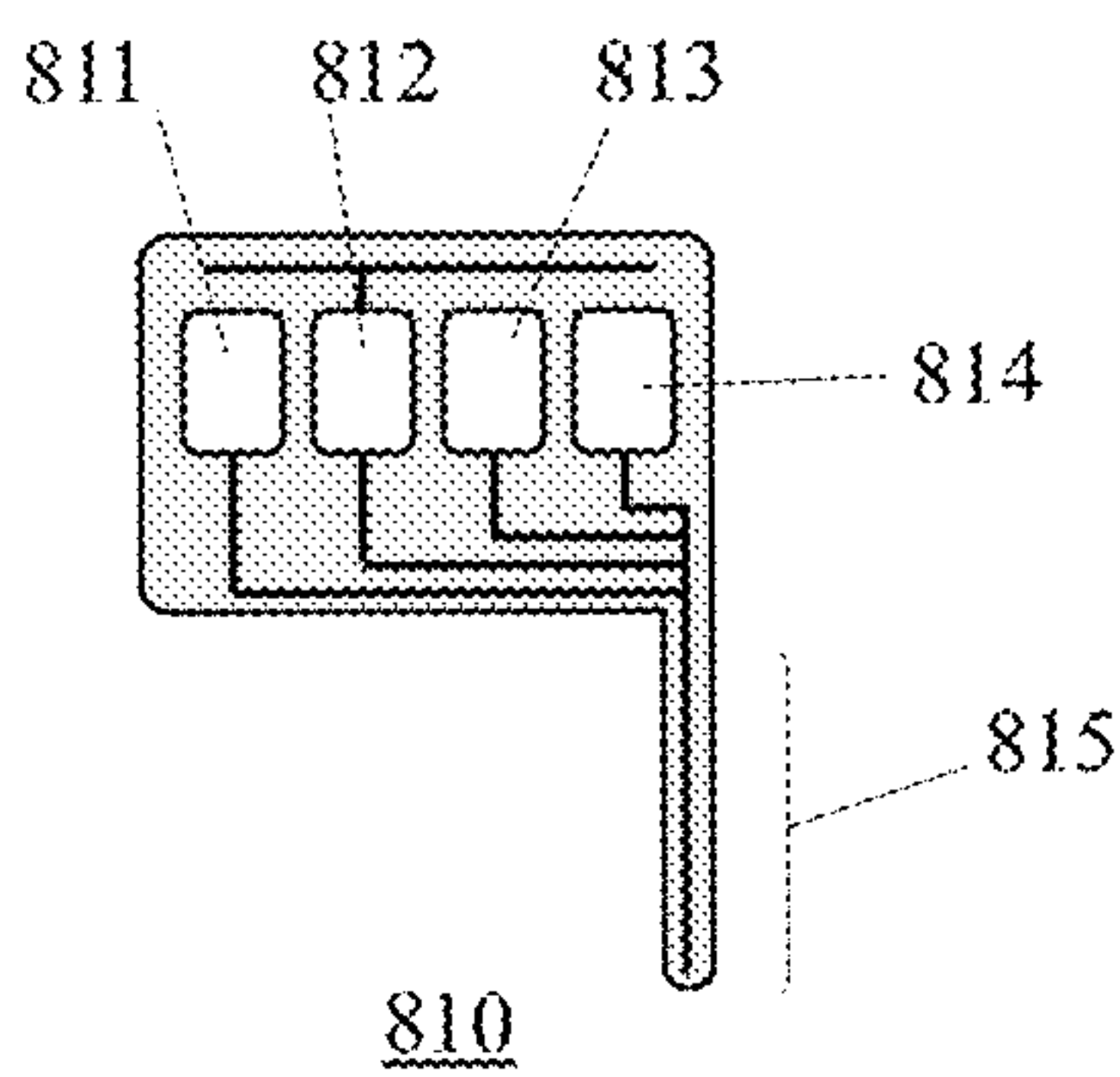


FIGURE 8A

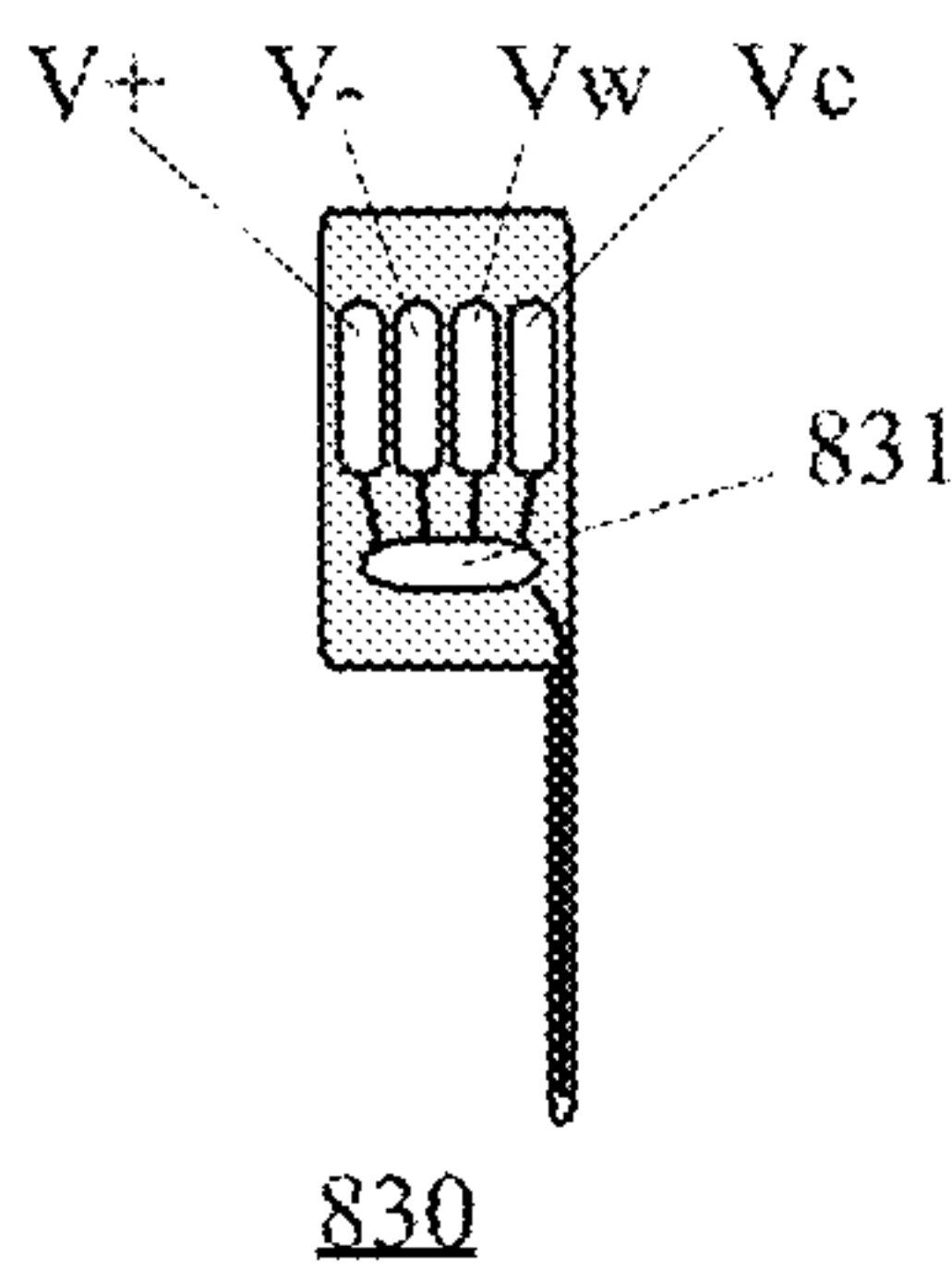


FIGURE 8C

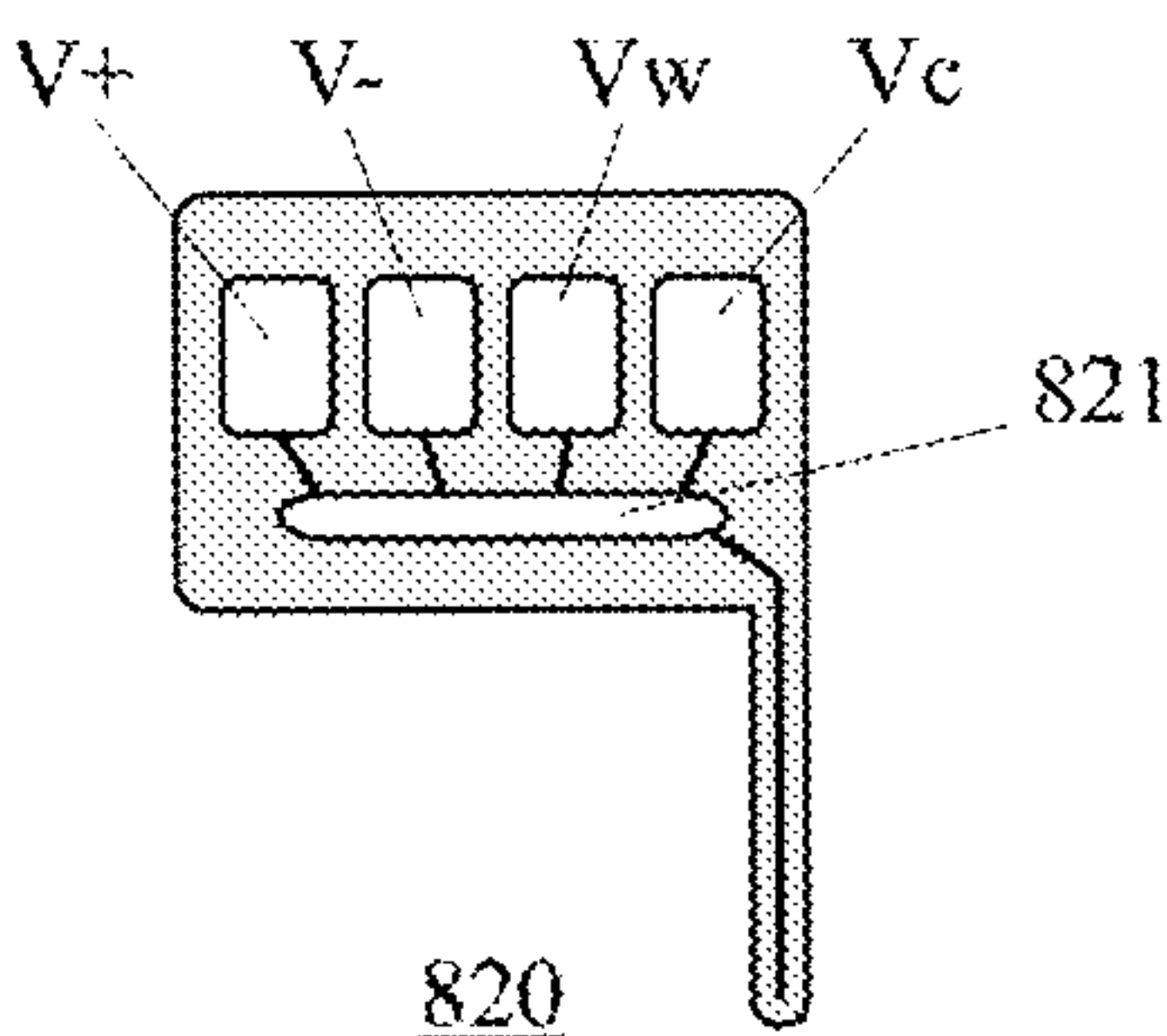
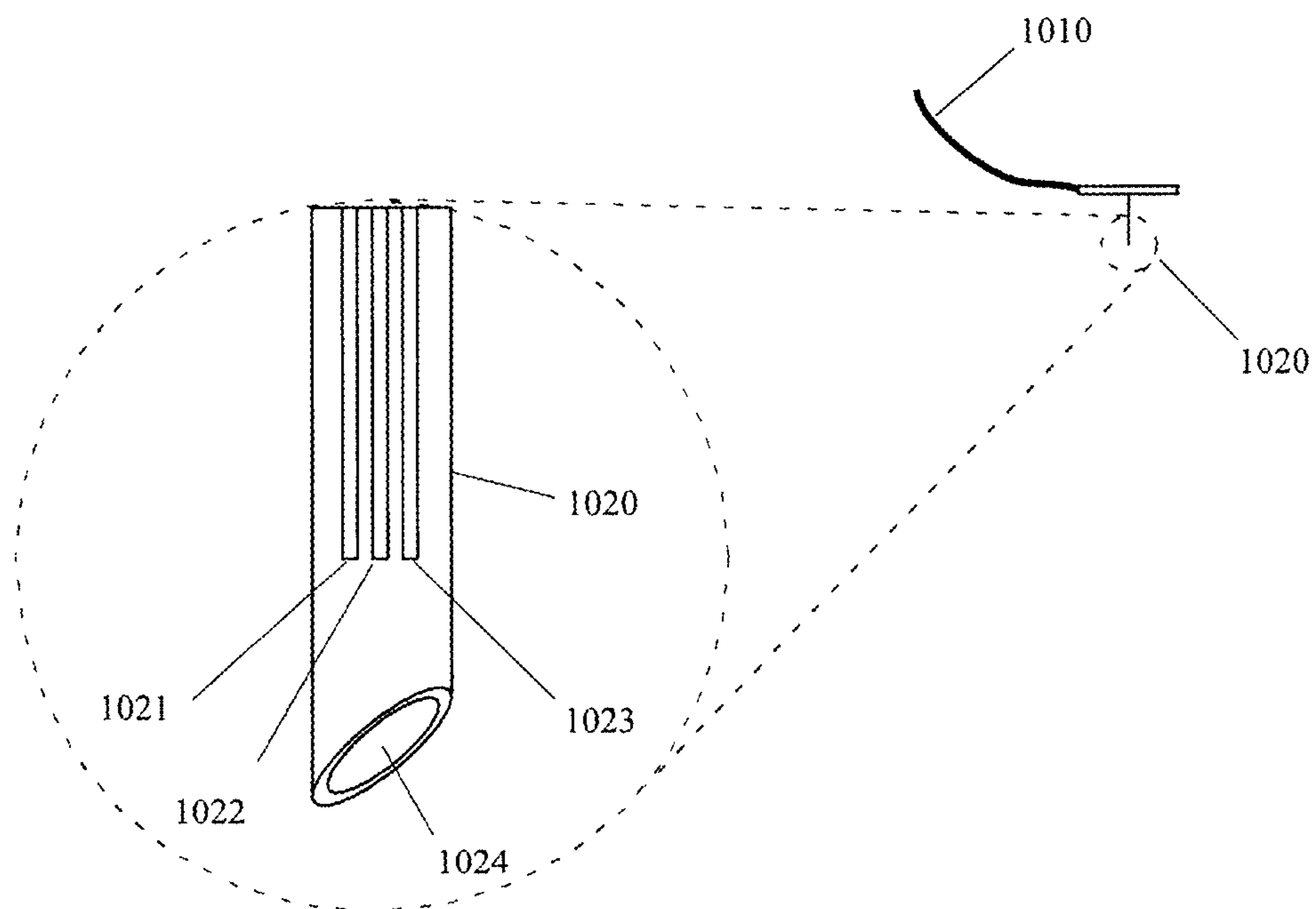
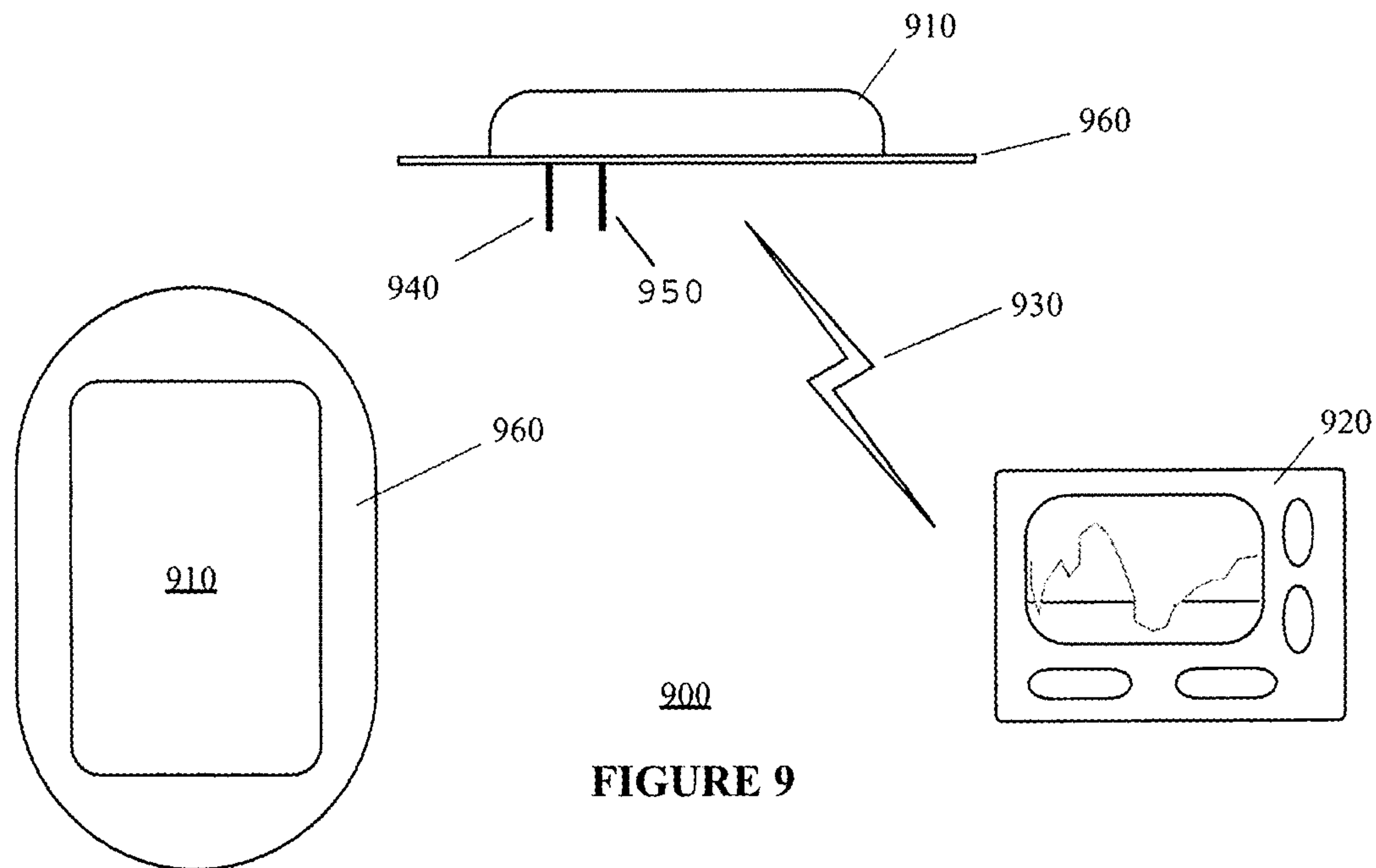


FIGURE 8B





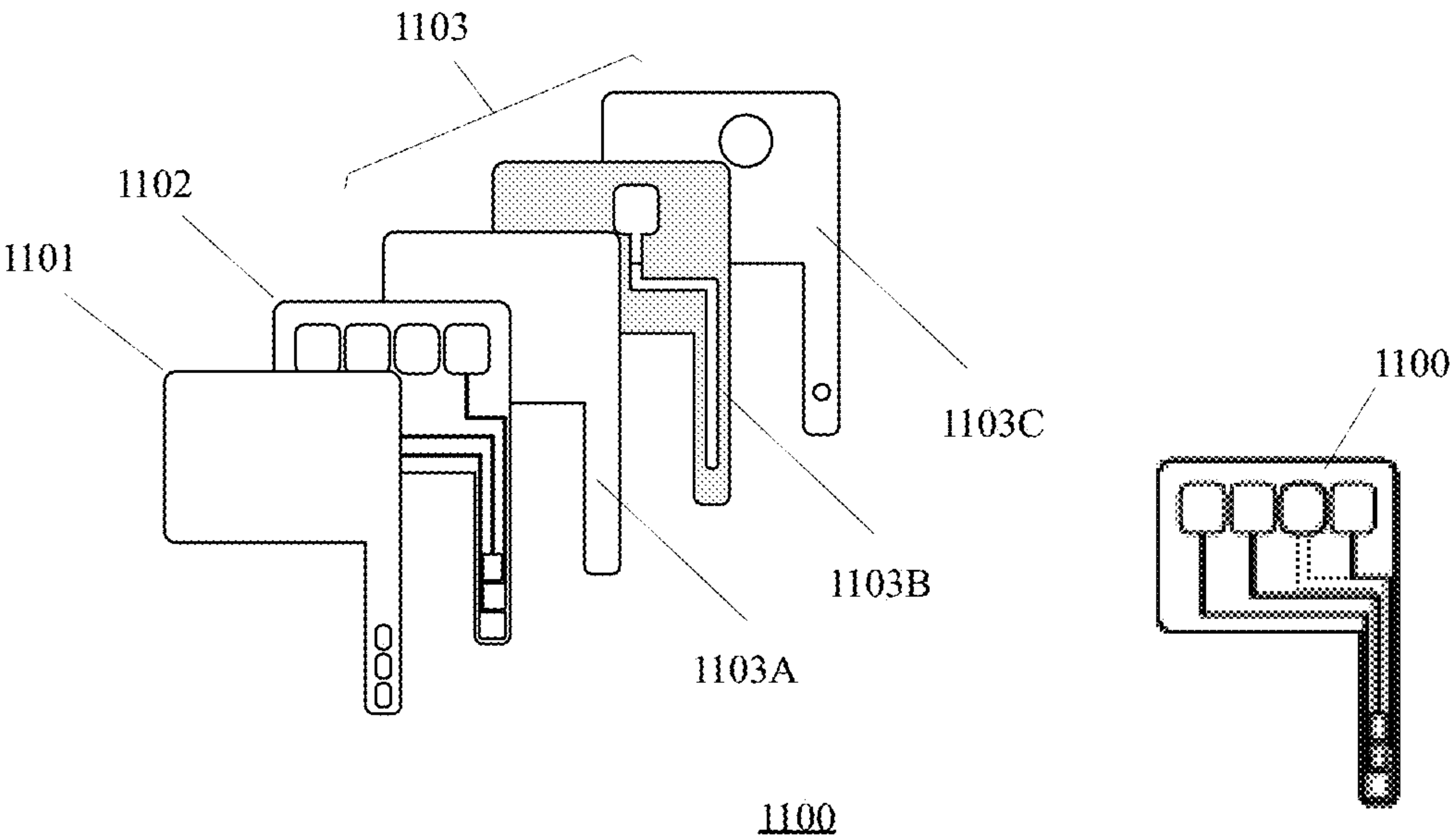


FIGURE 11A

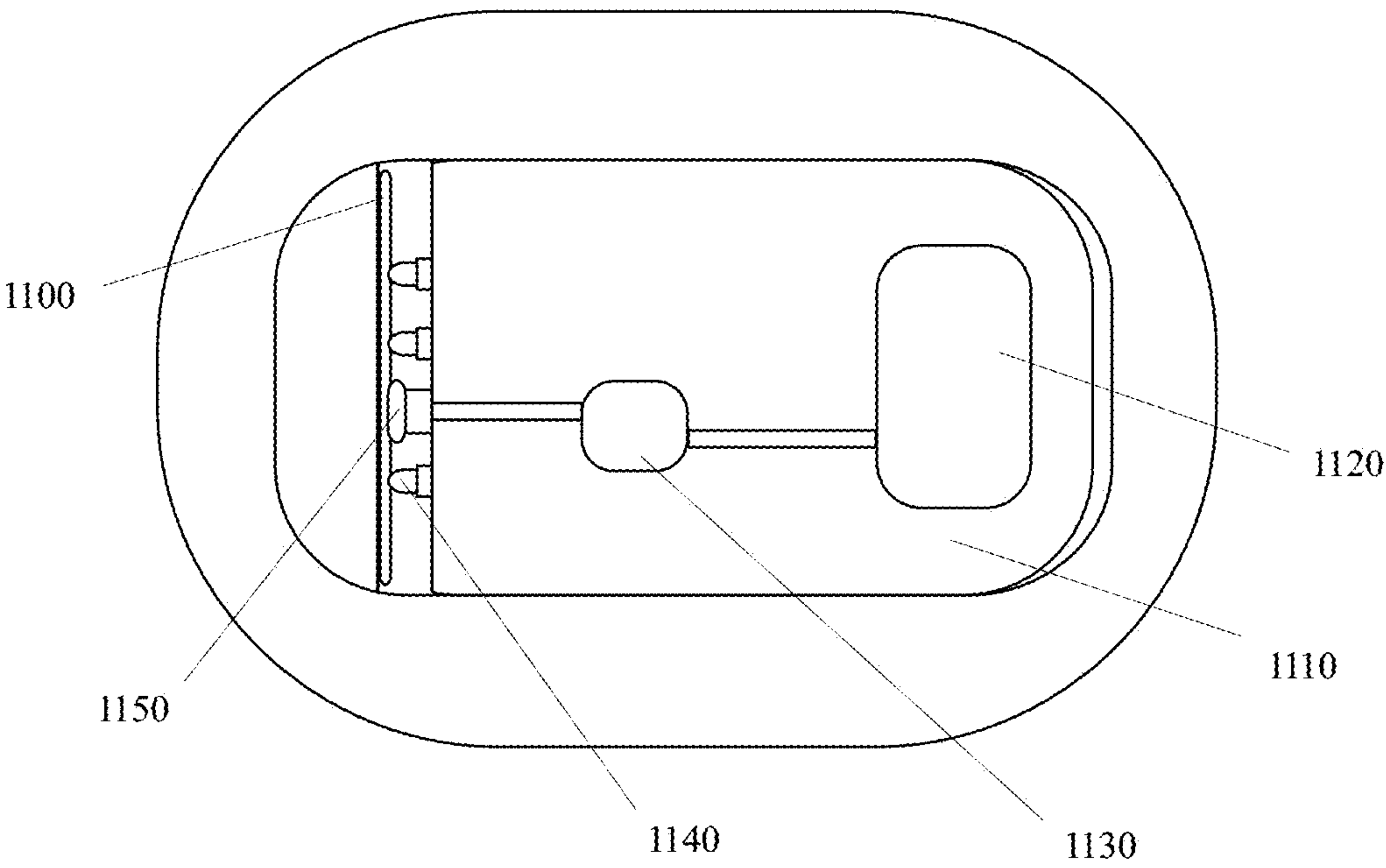


FIGURE 11B



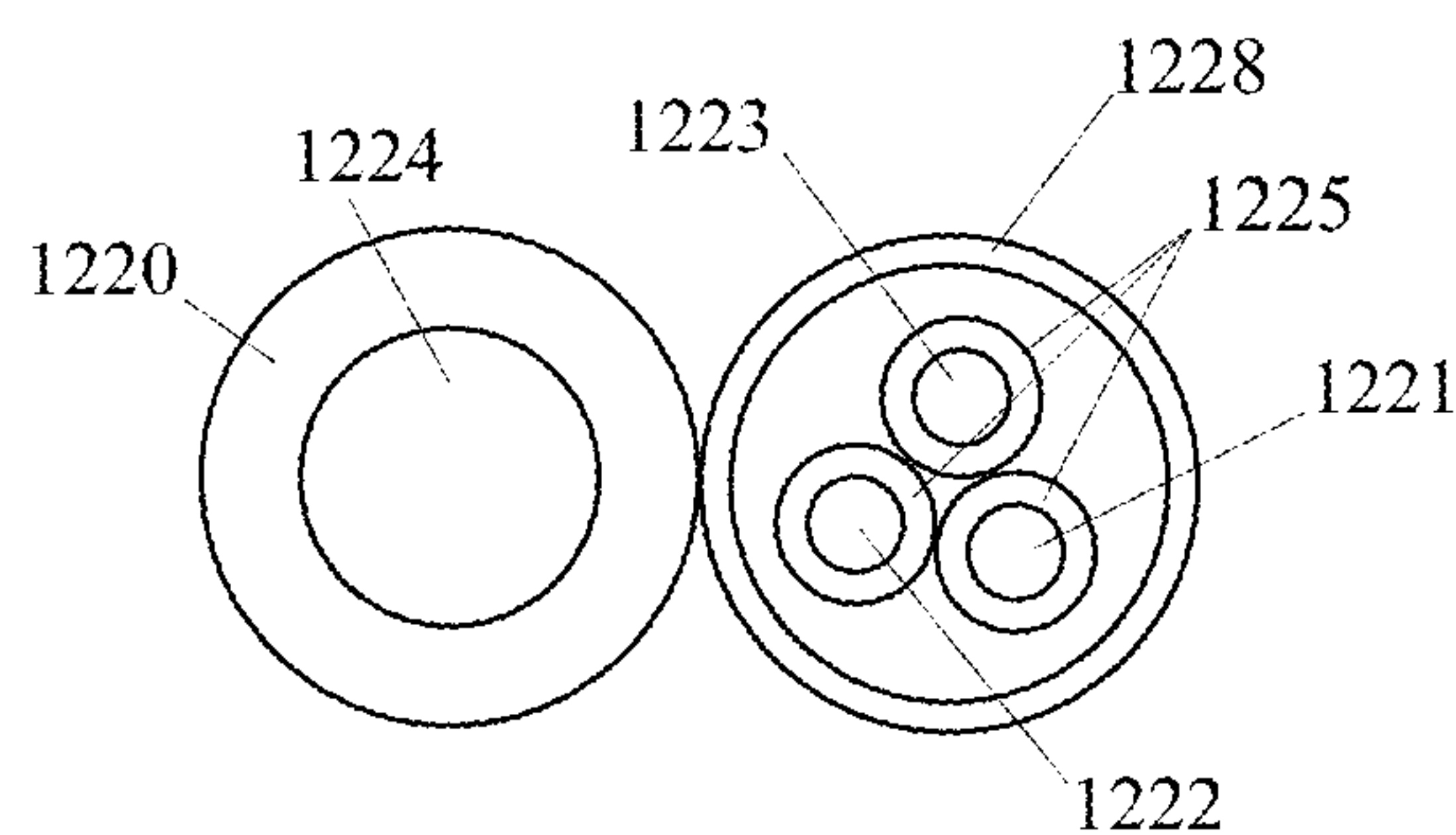


FIGURE 12A

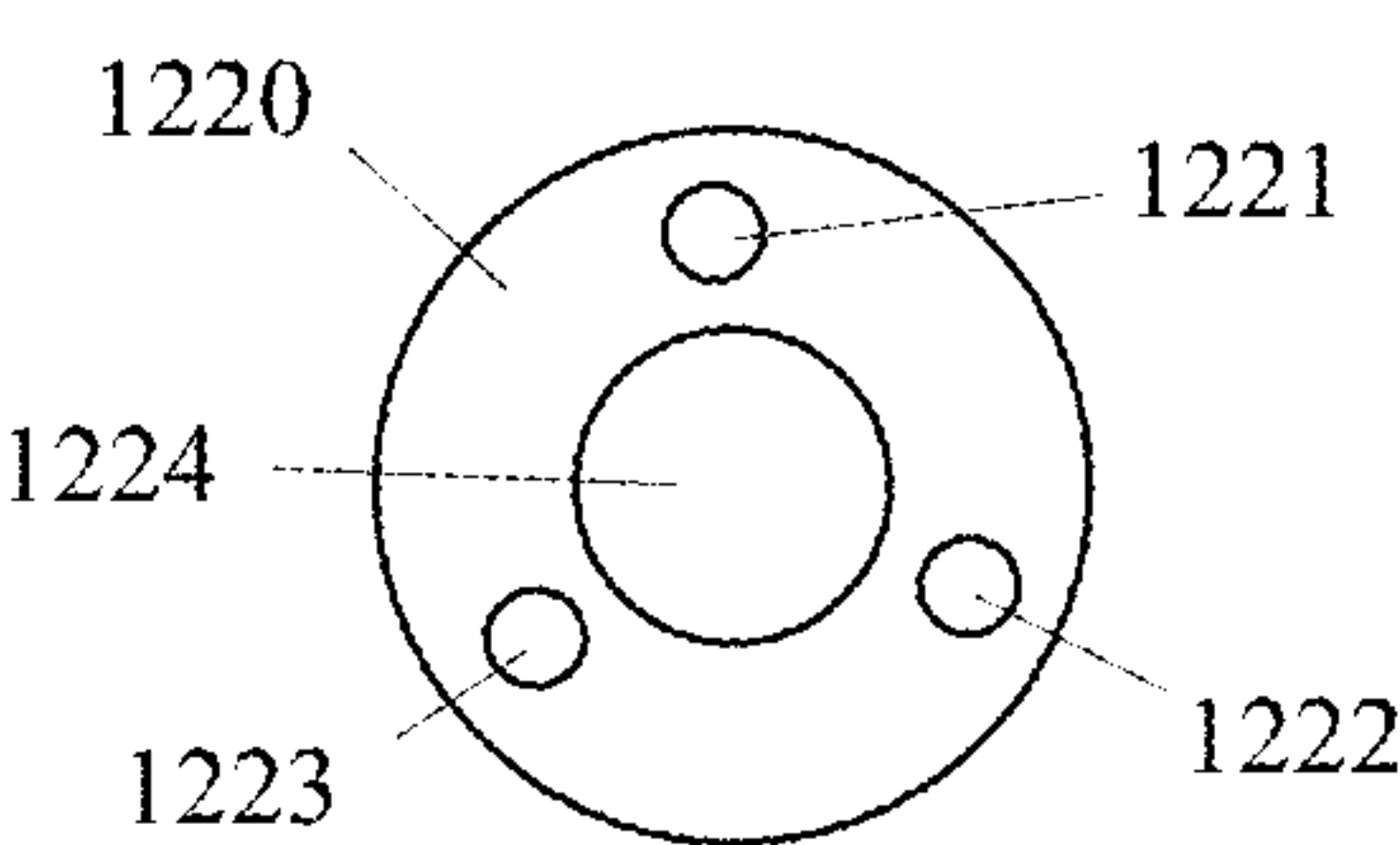


FIGURE 12B

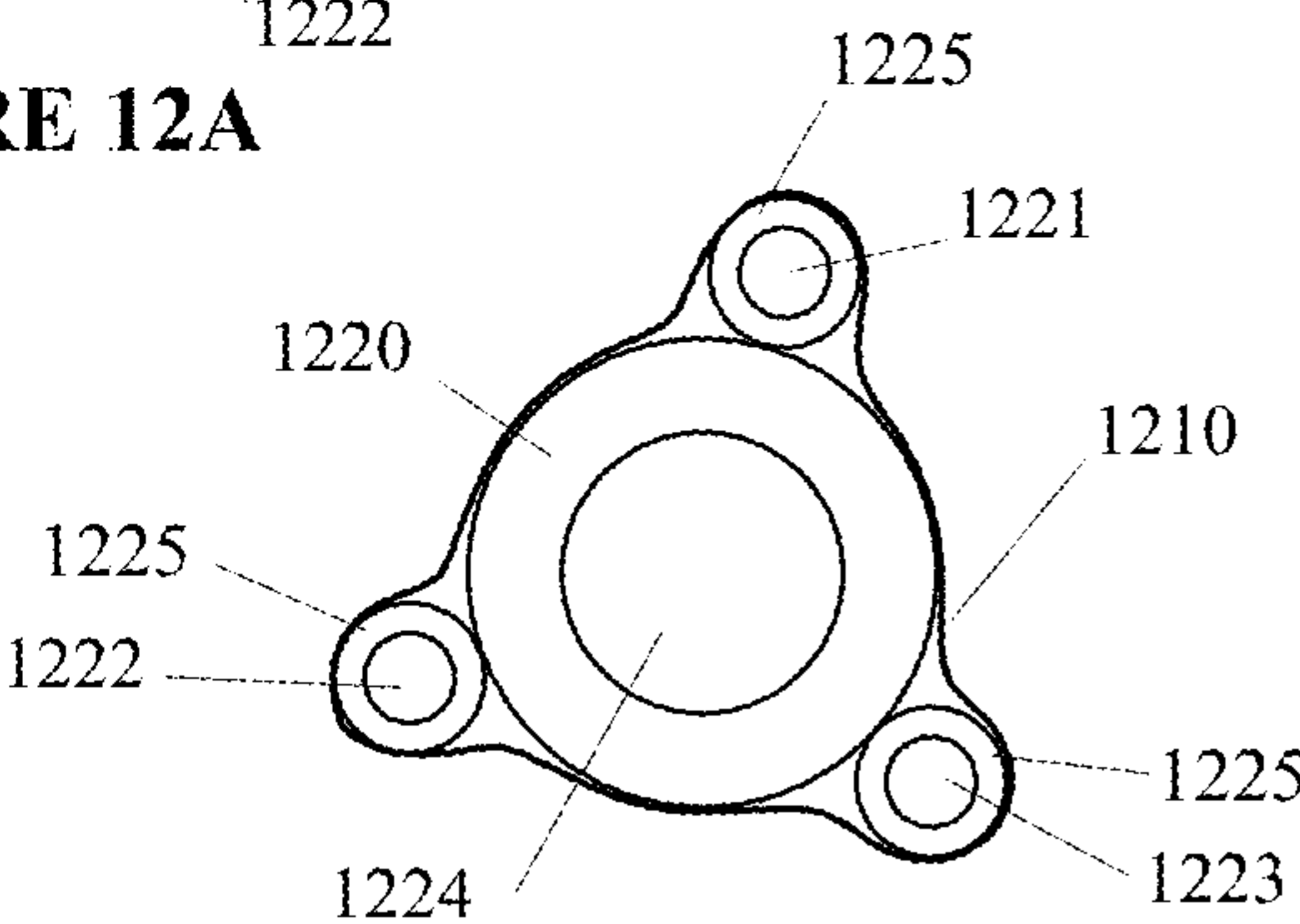


FIGURE 12C

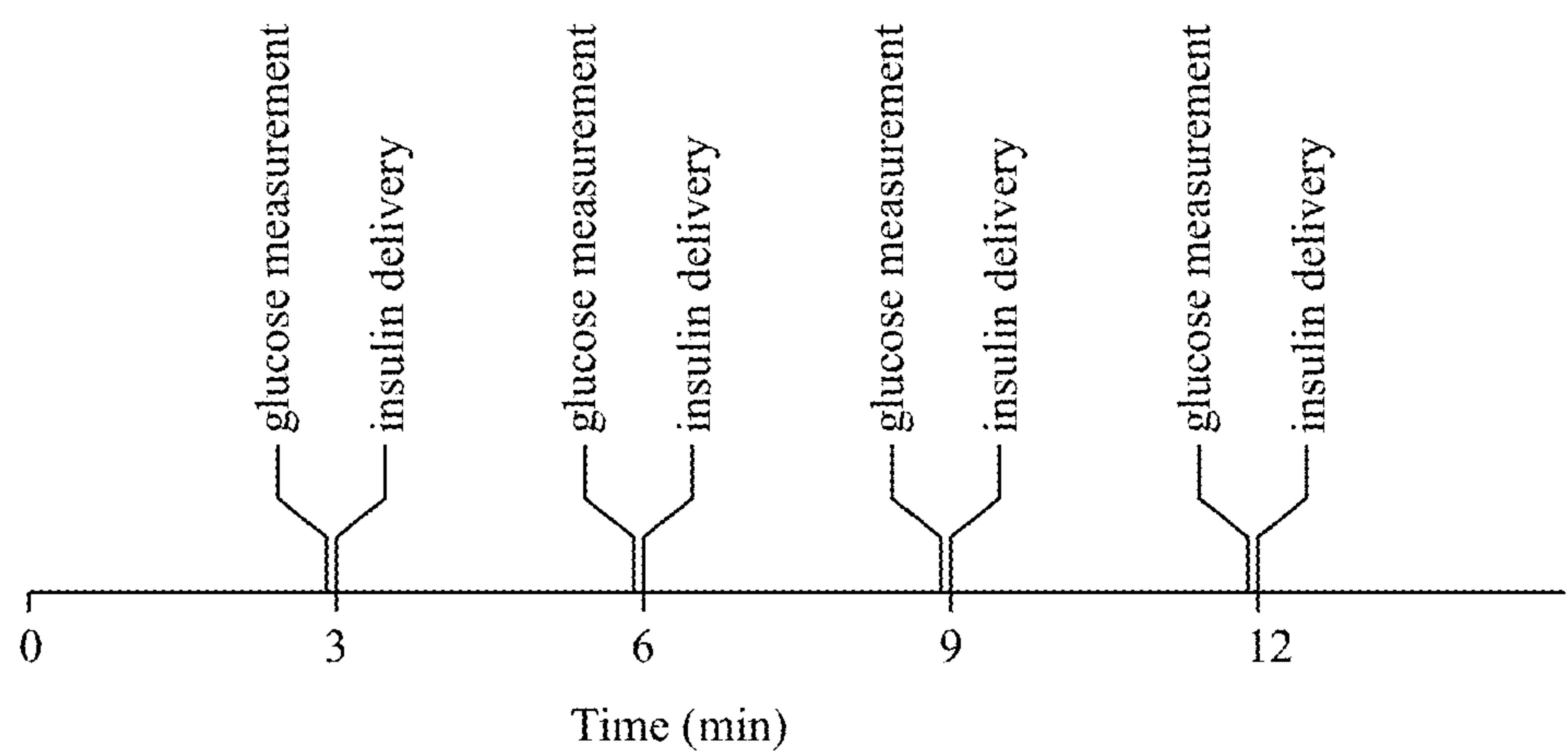


FIGURE 13

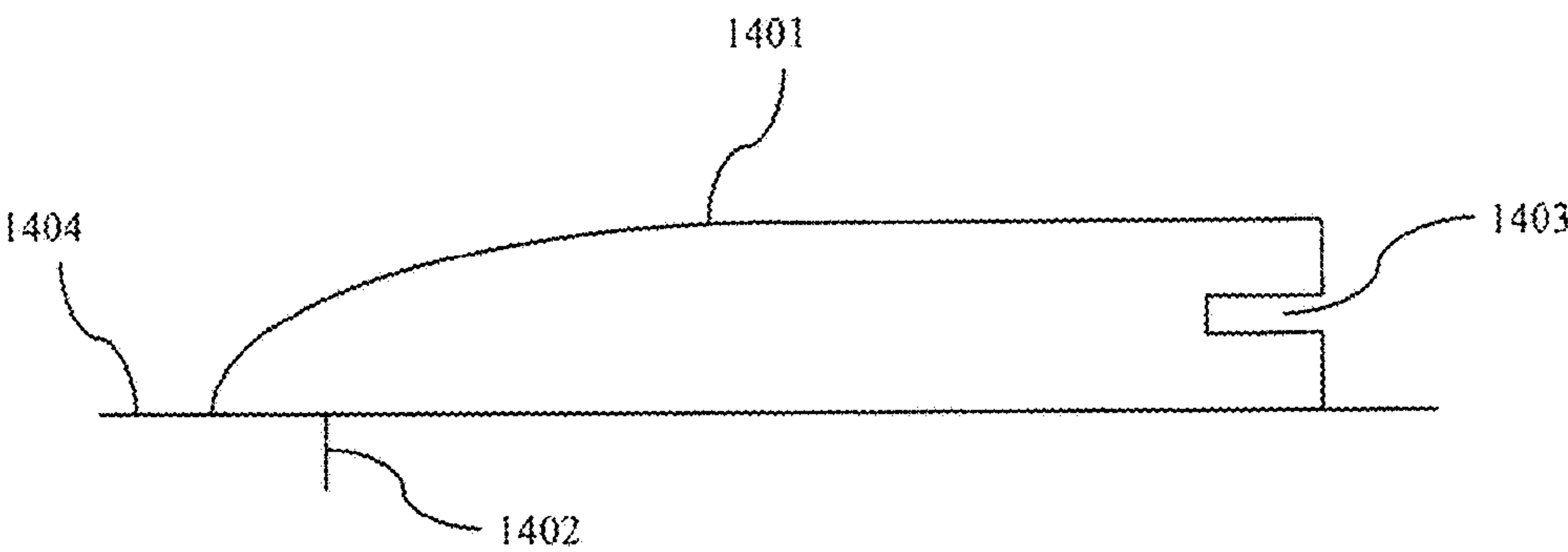


FIGURE 14A

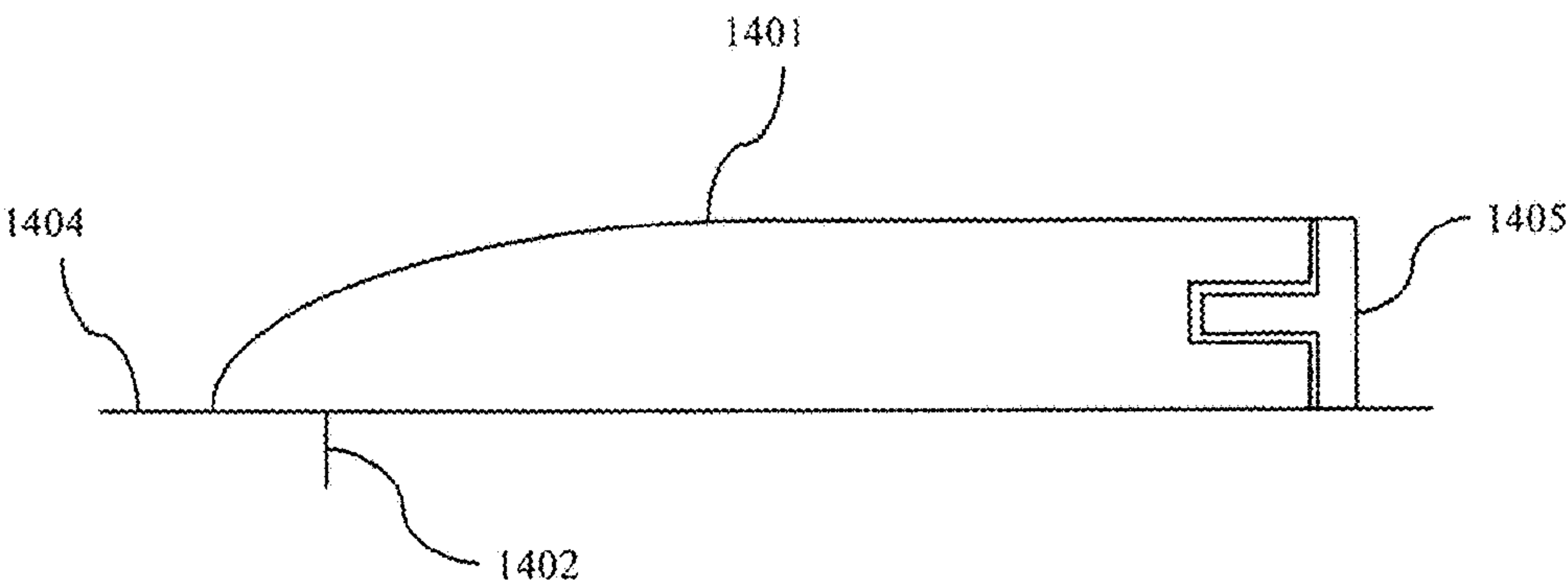


FIGURE 14B

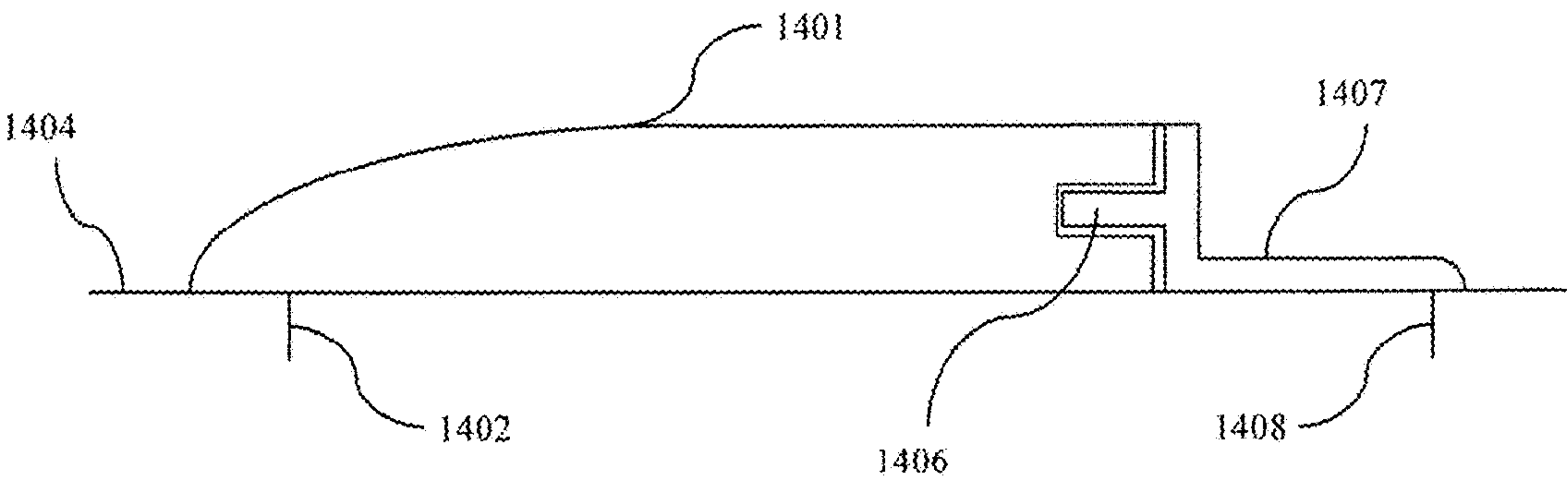


FIGURE 14C



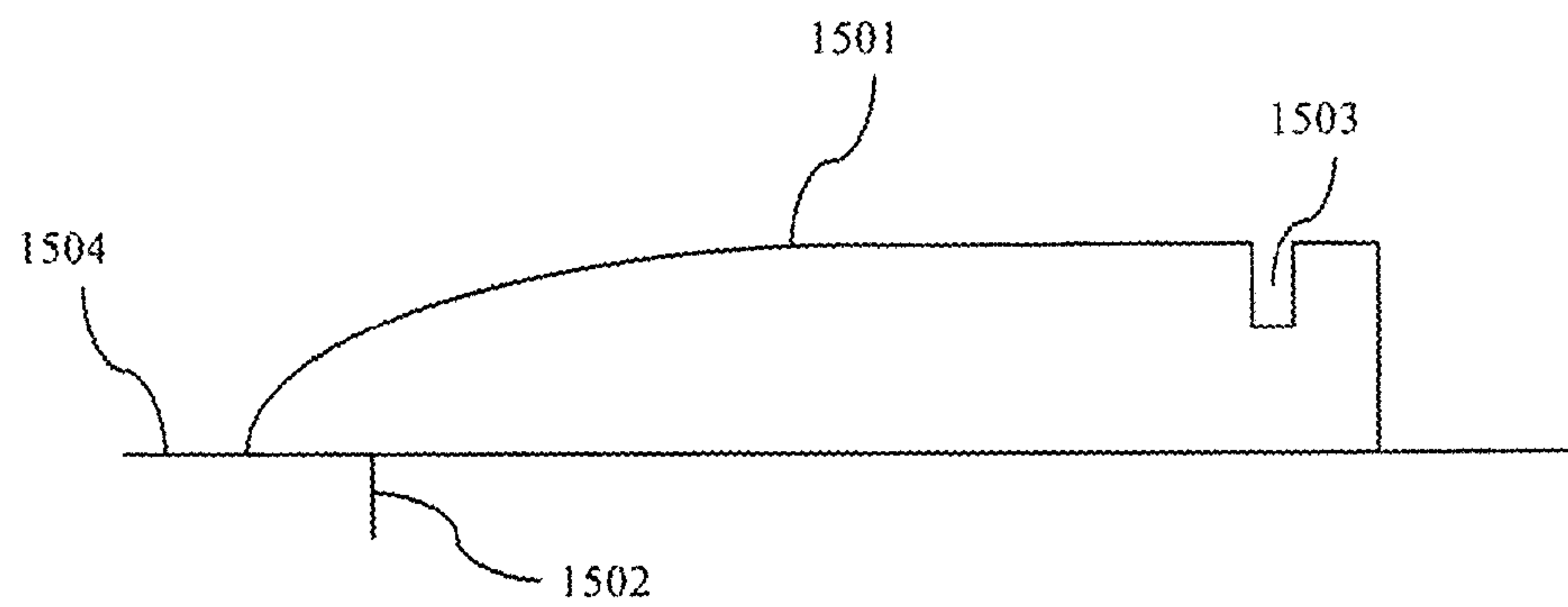


FIGURE 15A

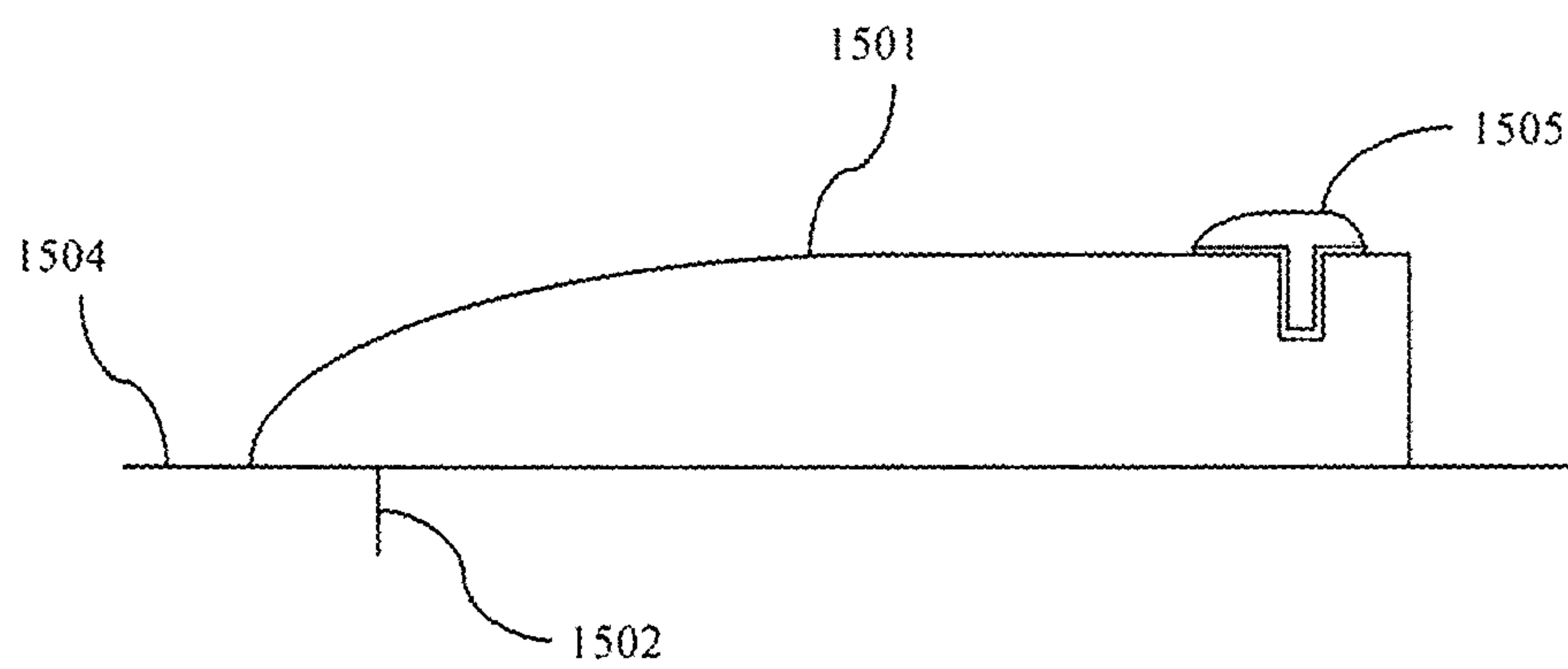


FIGURE 15B

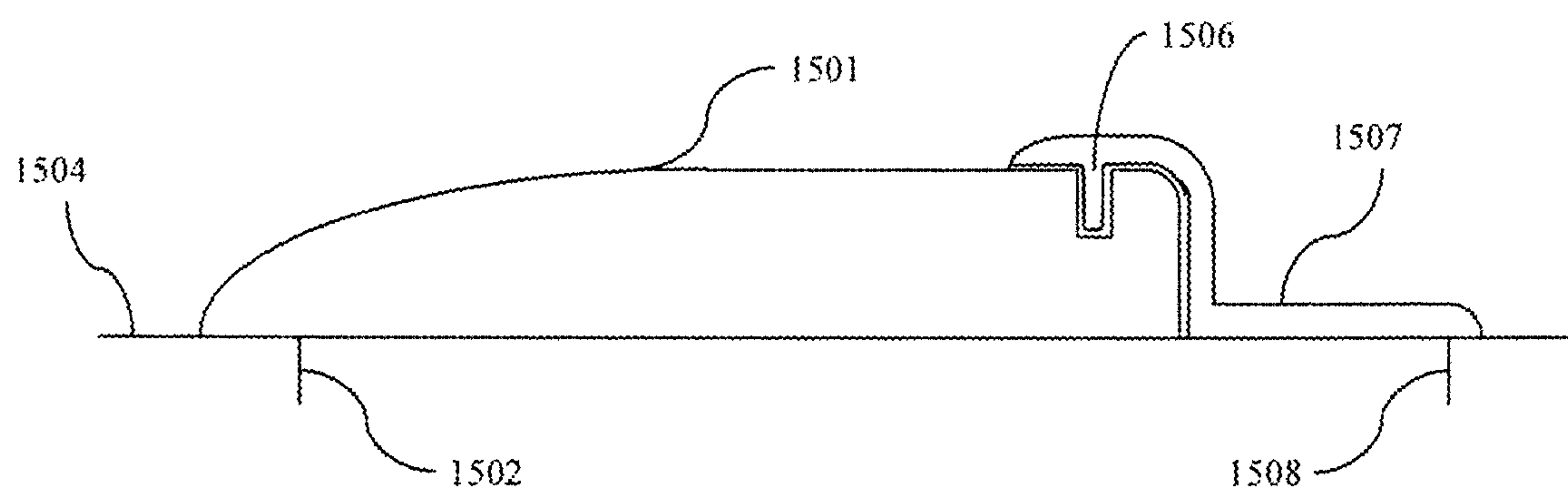


FIGURE 15C

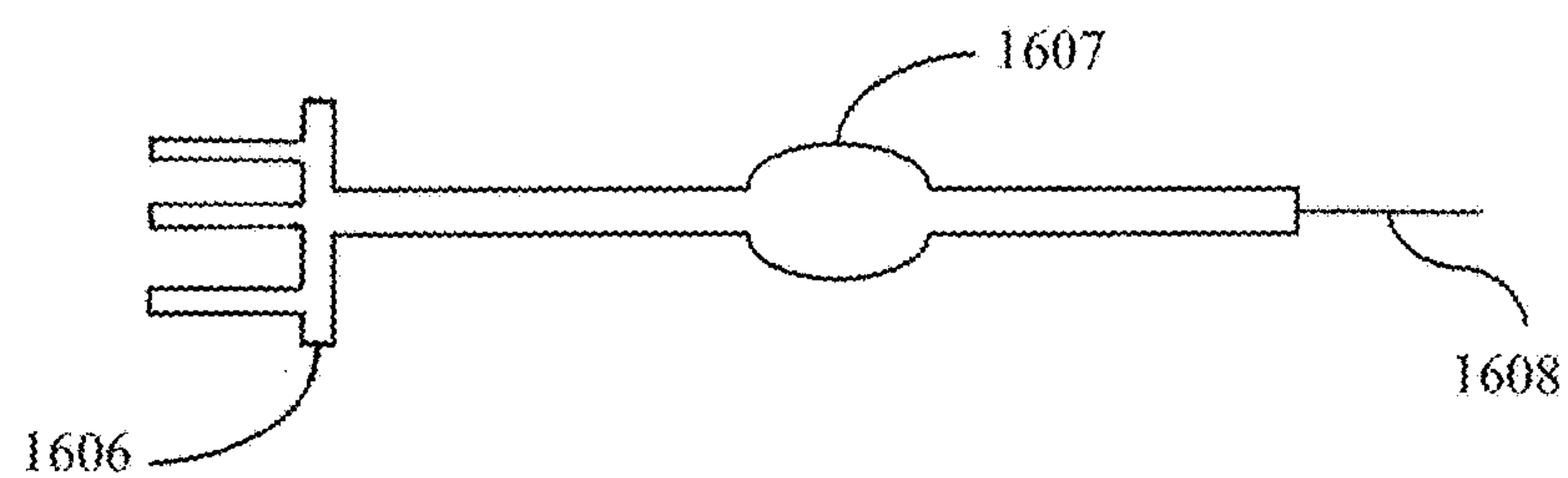


FIGURE 16

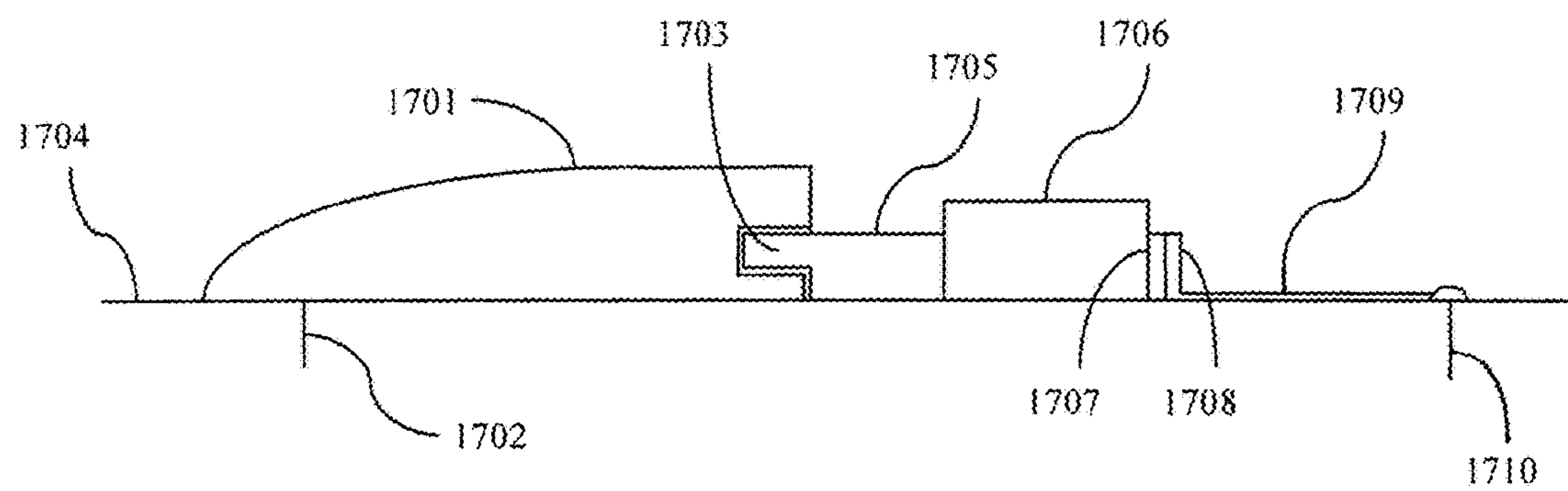


FIGURE 17



## 1

**PUMP SYSTEM MODULAR COMPONENTS  
FOR DELIVERING MEDICATION AND  
ANALYTE SENSING AT SEPERATE  
INSERTION SITES**

RELATED APPLICATION

The present application claims priority under §35 U.S.C. 119(e) to U.S. provisional patent application No. 60/890,497 filed Feb. 19, 2007, entitled "Modular Combination Of Medication Infusion And Analyte Monitoring", and assigned to the Assignee of the present application, Abbott Diabetes Care Inc. of Alameda, Calif., the disclosure of which is incorporated herein by reference for all purposes.

FIELD OF THE INVENTION

The present disclosure relates to methods and systems for integrating infusion systems and analyte monitoring systems. More specifically, the present disclosure relates to methods and systems for providing modular combination for integrated infusion and analyte monitoring systems.

BACKGROUND

Type 1 diabetics must periodically be administered with insulin to sustain their physiological conditions. Typically, these patients administer doses of either fast acting or slow acting insulin using needle type syringes, for example, prior to meals, and/or at a suitable time during the course of each day contemporaneously with the blood glucose level testing using fingerstick testing, for example. If insulin is not suitably administered, the diabetic patients risk serious if not fatal damage to the body.

Continued development and improvement in the external infusion pump therapy in recent years have drawn much appeal to the diabetic patients for, among others, improved management of diabetes by better regulating and controlling the intake of insulin. Typically, the patient inserts a cannula which is connected to as infusion tubing attached to an external pump, and insulin is administered based on a preprogrammed basal profiles. Moreover, the external infusion devices presently available include computational capability to determined suitable bolus doses such as carbohydrate bolus and correction bolus, for example, to be administered in conjunction with the infusion device executing the patient's basal profile.

The basal profiles are generally determined by the patient's physician or caretaker and are based on a number of factors including the patient's insulin sensitivity and physiological condition, which are diagnosed by the patient's physician, for example, and are typically intended to as accurately estimate the patient's glucose levels over a predetermined time period during which the patient is infusing insulin. The glucose levels may be estimated based on the patient's periodic discrete testing using a test strip and a blood glucose meter such as Freestyle® Glucose Meter available from Abbott Diabetes Care Inc., of Alameda, Calif. Such estimations are, however, prone to error, and do not accurately mirror the patient's actual physiological condition.

Furthermore, each aspect of the infusion and the analyte monitoring require components that are configured to execute the associated functions related to, for example, the control and management of insulin delivery and analyte monitoring. In addition, these components are prone to failure or otherwise periodic replacement due to ordinary

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usage. In view of the foregoing, it would be desirable to have a modular system including medication delivery unit such as an insulin pump, and an analyte monitoring device such as a continuous glucose monitoring system, that would allow for component based replacement when one or more aspects of the overall therapy management system fails or requires replacement.

SUMMARY

In accordance with the various embodiments of the present disclosure, there are provided method and system for modular combination of medication delivery and physiological condition monitoring.

These and other objects, features and advantages of the present disclosure will become more fully apparent from the following detailed description of the embodiments, the appended claims and the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 illustrates an integrated infusion device and analyte monitoring system in accordance with one embodiment of the present disclosure;

FIG. 2 illustrates an integrated infusion device and analyte monitoring system in accordance with another embodiment of the present disclosure;

FIG. 3 illustrates an integrated infusion device and analyte monitoring system in accordance with yet another embodiment of the present disclosure;

FIG. 4 illustrates an integrated infusion device and analyte monitoring system in accordance with still another embodiment of the present disclosure;

FIG. 5 illustrates an integrated infusion device and analyte monitoring system in accordance with still a further embodiment of the present disclosure;

FIG. 6 illustrates an integrated infusion device and monitoring system in accordance with yet still a further embodiment of the present disclosure;

FIG. 7A illustrates the integrated infusion device and monitoring system shown in FIG. 6 in further detail in one embodiment of the present disclosure, while FIGS. 7B-7C illustrate the analog front end circuitry located at the patient interface and the pump assembly, respectively, of the integrated infusion device and monitoring system shown in FIG. 7A in accordance with one embodiment of the present disclosure;

FIGS. 8A-8C illustrate a passive sensor configuration for use in a continuous analyte monitoring system, and two embodiments of an active sensor configuration for use at the patient interface in the integrated infusion device and monitoring system, respectively, in accordance with one embodiment of the present disclosure;

FIG. 9 illustrates an integrated infusion device and analyte monitoring system with the infusion device and the monitoring system transmitter integrated into a single patch worn by the patient in accordance with one embodiment of the present disclosure;

FIG. 10 is a detailed view of the infusion device cannula integrated with analyte monitoring system sensor electrodes in accordance with one embodiment of the present disclosure;

FIG. 11A illustrates a component perspective view of the infusion device cannula integrated with analyte monitoring system sensor electrodes in accordance with another embodiment of the present disclosure, while FIG. 11B illustrates a top planar view of the analyte monitoring



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system transmitter unit integrated with infusion device in accordance with one embodiment of the present disclosure;

FIGS. 12A-12C each illustrate a cross sectional view of the infusion device cannula integrated with continuous analyte monitoring system sensor electrodes of FIG. 10 in accordance with the various embodiments respectively, of the present disclosure;

FIG. 13 is a timing chart for illustrating the temporal spacing of blood glucose measurement and insulin delivery by the integrated infusion device and monitoring system in one embodiment;

FIGS. 14A-14C illustrate modular combination of medication delivery and physiological condition monitoring system in accordance with one embodiment;

FIGS. 15A-15C illustrate modular combination of medication delivery and physiological condition monitoring system in accordance with another embodiment;

FIG. 16 illustrates a top planar view of a modular sensor component in accordance with one embodiment; and

FIG. 17 illustrates modular combination of medication delivery and physiological condition monitoring system in accordance with yet another embodiment.

#### DETAILED DESCRIPTION

FIG. 1 illustrates an integrated infusion device and analyte monitoring system in accordance with one embodiment of the present disclosure. Referring to FIG. 1, the integrated infusion device and analyte monitoring system 100 in one embodiment of the present disclosure includes an infusion device 110 connected to an infusion tubing 130 for liquid transport or infusion, and which is further coupled to a cannula 170. As can be seen from FIG. 1, the cannula 170 is configured to be mountably coupled to a transmitter unit 150, where the transmitter unit 150 is also mountably coupled to an analyte sensor 160. Also provided is an analyte monitor unit 120 which is configured to wirelessly communicate with the transmitter unit over a communication path 140.

Referring to FIG. 1, in one embodiment of the present disclosure, the transmitter unit 150 is configured for unidirectional wireless communication over the communication path 140 to the analyte monitor unit 120. In one embodiment, the analyte monitor unit 120 may be configured to include a transceiver unit (not shown) for bidirectional communication over the communication path 140. The transmitter unit 150 in one embodiment may be configured to periodically or continuously transmit signals associated with analyte levels detected by the analyte sensor 160 to the analyte monitor unit 120. The analyte monitor unit 120 may be configured to receive the signals from the transmitter unit 150 and in one embodiment, is configured to perform data storage and processing based on one or more preprogrammed or predetermined processes.

For example, in one embodiment, the analyte monitor unit 120 is configured to store the received signals associated with analyte levels in a data storage unit (not shown). Alternatively, or in addition, the analyte monitor unit 120 may be configured to process the signals associated with the analyte levels to generate trend indication by, for example, visual display of a line chart or an angular icon based display for output display on its display unit 121. Additional information may be output displayed on the display unit 121 of the analyte monitor unit 120 including, but not limited to, the substantially contemporaneous and monitored real time analyte level of the patient received from the transmitter unit 150 as detected by the sensor 160. The real time monitored

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analyte level may be displayed in a numeric format or in any other suitable format which provides the patient with the accurate measurement of the substantially real time analyte level detected by the sensor 160.

Analytes that may be monitored or determined by the sensor 160 include, for example, acetyl choline, amylase, bilirubin, cholesterol, chorionic gonadotropin, creatine kinase (e.g., CK-MB), creatine, DNA, fructosamine, glucose, glutamine, growth hormones, hormones, ketones, lactate, peroxide, prostate-specific antigen, prothrombin, RNA, thyroid stimulating hormone, and troponin. The concentration of drugs, such as, for example, antibiotics (e.g., gentamicin, vancomycin, and the like), digitoxin, digoxin, drugs of abuse, theophylline, and warfarin, may also be determined.

Referring back to FIG. 1, the sensor 160 may include a short term (for example, 3 day, 5 day or 7 day use) analyte sensor which is replaced after its intended useful life. Moreover, in one embodiment, the sensor 160 is configured to be positioned subcutaneous to the skin of the patient such that at least a portion of the analyte sensor is maintained in fluid contact with the patient's analyte such as, for example, interstitial fluid or blood. In addition, the cannula 170 which is configured to similarly be positioned under the patient's skin is connected to the infusion tubing 130 of the infusion device 110 so as to deliver medication such as insulin to the patient. Moreover, in one embodiment, the cannula 170 is configured to be replaced with the replacement of the sensor 160.

In one aspect of the present disclosure, the cannula 170 and the sensor 160 may be configured to be subcutaneously positioned under the skin of the patient using an insertion mechanism (not shown) such as an insertion gun which may include, for example, a spring biased or loaded insertion mechanism to substantially accurately position the cannula 170 and the sensor 160 under the patient's skin. In this manner, the cannula 170 and the sensor 160 may be subcutaneously positioned with substantially little or no perceived pain by the patient. Alternatively, the cannula 170 and/or the sensor 160 may be configured to be manually inserted by the patient through the patient's skin. After positioning the cannula 170 and the sensor 160, they may be substantially firmly retained in position by an adhesive layer 180 which is configured to adhere to the skin of the patient for the duration of the time period during which the sensor 160 and the cannula 170 are subcutaneously positioned.

Moreover, in one embodiment, the transmitter unit 150 may be mounted after the subcutaneous positioning of the sensor 160 and the cannula 150 so as to be in electrical contact with the sensor electrodes. Similarly, the infusion tubing 130 may be configured to operatively couple to the housing of the transmitter unit 150 so as to be accurately positioned for alignment with the cannula 170 and to provide a substantially water tight seal. Exemplary analyte systems that may be employed are described in, for example, U.S. Pat. Nos. 6,134,461, 6,175,752, 6,121,611, 6,560,471, 6,746,582, and elsewhere.

Referring back to FIG. 1, the infusion device 110 may include capabilities to program basal profiles, calculation of bolus doses including, but not limited to, correction bolus, carbohydrate bolus, extended bolus, and dual bolus, which may be performed by the patient using the infusion device 110, and may be based on one or more factors including the patient's insulin sensitivity, insulin on board, intended carbohydrate intake (for example, for the carbohydrate bolus calculation prior to a meal), the patient's measured or detected glucose level, and the patient's glucose trend infor-



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mation. In a further embodiment, the bolus calculation capabilities may also be provided in the analyte monitor unit **120**.

In one embodiment, the analyte monitor unit **120** is configured with a substantially compact housing that can be easily carried by the patient. In addition, the infusion device **110** similarly may be configured as a substantially compact device which can be easily and conveniently worn on the patient's clothing (for example, housed in a holster or a carrying device worn or clipped to the patient's belt or other parts of the clothing). Referring yet again to FIG. **1**, the analyte monitor unit **120** and/or the infusion device **110** may include a user interface such as information input mechanism by the patient as well as data output including, for example, the display unit **121** on the analyte monitor unit **120**, or similarly a display unit **111** on the infusion device **110**.

One or more audio output devices such as, for example, speakers or buzzers may be integrated with the housing of the infusion device **110** and/or the analyte monitor unit **120** so as to output audible alerts or alarms based on the occurrence of one or more predetermined conditions associated with the infusion device **110** or the analyte monitor unit **120**. For example, the infusion device **110** may be configured to output an audible alarm or alert to the patient upon detection of an occlusion in the infusion tubing **130** or the occurrence of a timed event such as a reminder to prime the infusion tubing upon replacement of the cannula **170**, and the like.

The analyte monitor unit **120** may be similarly configured to output an audible alarm or alert when a predetermined condition or a pre-programmed event occurs, such as, for example, a reminder to replace the sensor **160** after its useful life (of, for example, 3 days, 5 days or 7 days, or more), or one or more alerts associated with the data received from the transmitter unit **150** corresponding to the patient's monitored analyte levels. Such alerts or alarms may include a warning alert to the patient that the detected analyte level is beyond a predetermined threshold level, or the trend of the detected analyte levels within a given time period is indicative of a significant condition such as potential hyperglycemia or hypoglycemia, which require attention or corrective action. It is to be noted that the examples of audible alarms and/or alerts are described above for illustrative purposes only, that within the scope of the present disclosure, other events or conditions may be programmed into the infusion device **110** or the analyte monitor unit **120** or both, so as to alert or notify the patient of the occurrence or the potential occurrence of such events or conditions.

In addition, within the scope of the present disclosure, audible alarms may be output alone, or in combination with one or more of a visual alert such as an output display on the display unit **111**, **121** of the infusion device **110** or the analyte monitor unit **120**, respectively, or vibratory alert which would provide a tactile indication to the patient of the associated alarm and/or alert.

Moreover, referring yet again to FIG. **1**, while one analyte monitor unit **120** and one transmitter unit **150** are shown, within the scope of the present disclosure, additional analyte monitor units or transmitter units may be provided such that, for example, the transmitter unit **150** may be configured to transmit to multiple analyte monitor units substantially simultaneously. Alternatively, multiple transmitter units coupled to multiple sensors concurrently in fluid contact with the patient's analyte may be configured to transmit to the analyte monitor unit **120**, or to multiple analyte monitor units. For example, an additional transmitter unit coupled to

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an additional sensor may be provided in the integrated infusion device and analyte monitoring system **100** which does not include the cannula **170**, and which may be used to perform functions associated with the sensor **160** such as sensor calibration, sensor data verification, and the like.

In one embodiment, the transmitter unit **150** is configured to transmit the sampled data signals received from the sensor **160** without acknowledgement from the analyte monitor unit **120** that the transmitted sampled data signals have been received. For example, the transmitter unit **150** may be configured to transmit the encoded sampled data signals at a fixed rate (e.g., at one minute intervals, or any suitable rate) after the completion of the initial power on procedure. Likewise, the analyte monitor unit **120** may be configured to detect such transmitted encoded sampled data signals at predetermined time intervals. Alternatively, the transmitter unit **150** and the analyte monitor unit **120** may be configured for bi-directional communication over the communication path **140**.

Additionally, in one aspect, the analyte monitor unit **120** may include two sections. The first section of the analyte monitor unit **120** may include an analog interface section that is configured to communicate with the transmitter unit **150** via the communication path **140**. In one embodiment, the analog interface section may include an RF receiver and an antenna for receiving and amplifying the data signals from the transmitter unit **150**, which are thereafter, demodulated with a local oscillator and filtered through a band-pass filter. The second section of the analyte monitor unit **120** may include a data processing section which is configured to process the data signals received from the transmitter unit **150** such as by performing data decoding, error detection and correction, data clock generation, and data bit recovery, for example.

In operation, upon completing the power-on procedure, the analyte monitor unit **120** is configured to detect the presence of the transmitter unit **150** within its range based on, for example, the strength of the detected data signals received from the transmitter unit **150** or predetermined transmitter identification information. Upon successful synchronization with the transmitter unit **150**, the analyte monitor unit **120** is configured to begin receiving from the transmitter unit **150** data signals corresponding to the patient's detected analyte, for example glucose, levels.

Referring again to FIG. **1**, the analyte monitor unit **120** or the infusion device **110**, or both may be configured to further communicate with a data processing terminal (not shown) which may include a desktop computer terminal, a data communication enabled kiosk, a laptop computer, a handheld computing device such as a personal digital assistant (PDAs), or a data communication enabled mobile telephone, and the like, each of which may be configured for data communication via a wired or a wireless connection. The data processing terminal for example may include physician's terminal and/or a bedside terminal in a hospital environment.

The communication path **140** for data communication between the transmitter unit **150** and the analyte monitor unit **120** of FIG. **1** may include an RF communication link, Bluetooth® communication link, infrared communication link, or any other type of suitable wireless communication connection between two or more electronic devices. The data communication link may also include a wired cable connection such as, for example, but not limited to, an RS232 connection, USB connection, or serial cable connection.



Referring yet again to FIG. 1, in a further aspect of the present disclosure, the analyte monitor unit **120** or the infusion device **110** (or both) may also include a test strip port configured to receive a blood glucose test strip for discrete sampling of the patient's blood for glucose level determination. An example of the functionality of blood glucose test strip meter unit may be found in Freestyle® Blood Glucose Meter available from the assignee of the present disclosure, Abbott Diabetes Care Inc.

In the manner described above, in one embodiment of the present disclosure, the cannula **170** for infusing insulin or other suitable medication is integrated with the adhesive patch **180** for the sensor **160** and the transmitter unit **150** of the analyte monitoring system. Accordingly, only one on-skin patch can be worn by the patient (for example, on the skin of the abdomen) rather than two separate patches for the infusion device cannula **170**, and the analyte monitoring system sensor **160** (with the transmitter unit **150**). Thus, the Type-1 diabetic patient may conveniently implement infusion therapy in conjunction with real time glucose monitoring while minimizing potential skin irritation on the adhesive patch **180** site on the patient's skin, and thus provide more insertion sites with less irritation.

In addition, the integrated infusion device and analyte monitoring system **100** as shown in FIG. 1 may be configured such that the infusion tubing **130** may be disconnected from the infusion device **110** as well as from the housing of the transmitter unit **150** (or the adhesive patch **180**) such that, optionally, the patient may configure the system as continuous analyte monitoring system while disabling the infusion device **110** functionality. Likewise, a patient may configure the system as an infusion device while disabling the continuous analyte monitoring system functions.

Moreover, in accordance with one embodiment of the present disclosure, the patient may better manage the physiological conditions associated with diabetes by having substantially continuous real time glucose data, trend information based on the substantially continuous real time glucose data, and accordingly, modify or adjust the infusion levels delivered by the infusion device **110** from the pre-programmed basal profiles that the infusion device **110** is configured to implement.

FIG. 2 illustrates an integrated infusion device and analyte monitoring system in accordance with another embodiment of the present disclosure. Referring to FIG. 2, the integrated infusion device and analyte monitoring system **200** in one embodiment of the present disclosure includes an integrated infusion device and analyte monitor unit **210** which is coupled to an infusion tubing **220** connected to the cannula **260**. Also shown in FIG. 2 is a transmitter unit **240** which is in electrical contact with an analyte sensor **250**, where the cannula **260** and the analyte sensor **250** are subcutaneously positioned under the skin of the patient, and retained in position by an adhesive layer or patch **270**.

Referring to FIG. 2, the integrated infusion device and analyte monitor unit **210** is configured to wirelessly communicate with the transmitter unit **240** over a communication path **230** such as an RF communication link. Compared with the embodiment shown in FIG. 1, it can be seen that in the embodiment shown in FIG. 2, the infusion device and the analyte monitor are integrated into a single housing **210**. In this manner, the transmitter unit **240** may be configured to transmit signals corresponding to the detected analyte levels received from the analyte sensor **250** to the integrated infusion device and analyte monitor unit **210** for data analysis and processing.

Accordingly, the patient may conveniently receive real time glucose levels from the transmitter unit **240** and accordingly, determine whether to modify the existing basal profile(s) in accordance with which insulin is delivered to the patient. In this manner, the functionalities of the analyte monitor unit may be integrated within the compact housing of the infusion device to provide additional convenience to the patient, for example, by providing the real time glucose data as well as other relevant information such as glucose trend data to the user interface of the infusion device, so that the patient may readily and easily determine any suitable modification to the infusion rate of the insulin pump.

In one embodiment, the configurations of each component shown in FIG. 2 including the cannula **260**, the analyte sensor **250**, the transmitter unit **240**, the adhesive layer **270**, the communication path **230**, as well as the infusion tubing **220** and the functionalities of the infusion device and the analyte monitor are substantially similar to the corresponding respective component as described above in conjunction with FIG. 1.

Accordingly, in one embodiment of the present disclosure, the additional convenience may be provided to the patient in maintaining and enhancing diabetes management by, for example, having a single integrated device such as the integrated infusion device and analyte monitor unit **210** which would allow the patient to easily manipulate and manage insulin therapy using a single user interface system of the integrated infusion device and analyte monitor unit **210**. Indeed, by providing the information associated with both the glucose levels and insulin infusion in a single device, the patient may be provided with the additional convenience in managing diabetes and improving insulin therapy.

FIG. 3 illustrates an integrated infusion device and analyte monitoring system in accordance with yet another embodiment of the present disclosure. Referring to FIG. 3, the integrated infusion device and analyte monitoring system **300** in one embodiment of the present disclosure includes an infusion device **310** connected to an infusion tubing **340** coupled to a cannula **370**. The cannula **370** is configured to be positioned subcutaneously under the patient's skin and substantially retained in position by an adhesive layer **380**. Also retained in position, as discussed above and similar to the embodiments described in conjunction with FIGS. 1-2, is an analyte sensor **360** also positioned subcutaneously under the patient's skin and maintained in fluid contact with the patient's analyte. A transmitter unit **350** is provided so as to be electrically coupled to the analyte sensor **360** electrodes. Also, as can be seen from FIG. 3, in one embodiment, the infusion tubing **340** is connected to the housing of the transmitter unit **350** so as to connect to the cannula **370** disposed under the patient's skin.

Referring to FIG. 3, also provided is an analyte monitor unit **320** configured to wirelessly communicate with the transmitter unit **350** to receive data therefrom associated with the analyte levels of the patient detected by the analyte sensor **360**. Referring to FIG. 3, in one embodiment, the infusion device **310** does not include a user interface such as a display unit and/or an input unit such as buttons or a jog dial. Instead, the user interface and control mechanism is provided on the analyte monitoring unit **320** such that the analyte monitoring unit **320** is configured to wirelessly control the operation of the infusion device **310** and further, to suitably program the infusion device **310** to execute pre-programmed basal profile(s), and to otherwise control the functionality of the infusion device **310**.



More specifically, all of the programming and control mechanism for the infusion device **310** is provided in the analyte monitoring unit **320** such that when the patient is wearing the infusion device **310**, it may be worn discreetly under clothing near the infusion site on the patient's skin (such as abdomen), while still providing convenient access to the patient for controlling the infusion device **310** through the analyte monitoring unit **320**.

In addition, in one embodiment, the configurations of each component shown in FIG. 3 including the cannula **370**, the analyte sensor **360**, the transmitter unit **350**, the adhesive layer **380**, the communication path **330**, as well as the infusion tubing **340** and the functionalities of the infusion device and the analyte monitoring unit **320** are substantially similar to the corresponding respective component as described above in conjunction with FIG. 1. However, the infusion device **310** in the embodiment shown in FIG. 3 is configured with a transceiver or an equivalent communication mechanism to communicate with the analyte monitoring unit **320**.

In this manner, in one embodiment of the present disclosure, configuration of the infusion device **310** without a user interface provides a smaller and lighter housing and configuration for the infusion device **310** which would enhance the comfort in wearing and/or carrying the infusion device **310** with the patient. Moreover, since the control and programming functions of the infusion device **310** is provided on the analyte monitoring unit **320**, the patient may conveniently program and/or control the functions and operations of the infusion device **310** without being tethered to the infusion tubing **340** attached to the cannula **370**, which is positioned under the patient's skin. In addition, since the programming and control of the infusion device **310** is remotely performed on the analyte monitoring unit **320**, the infusion tubing **340** may be shorter and thus less cumbersome.

FIG. 4 illustrates an integrated infusion device and analyte monitoring system in accordance with still another embodiment of the present disclosure. Referring to FIG. 4, the integrated infusion device and analyte monitoring system **400** in one embodiment of the present disclosure includes an infusion device **410** configured to wirelessly communicate with an analyte monitoring unit **420** over a communication path **430** such as an RF (radio frequency) link. In addition, as can be further seen from FIG. 4, the infusion device **410** is connected to an infusion tubing **440** which has provided therein integral wires connected to the analyte sensor electrodes. As discussed in further detail below, the measured analyte levels of the patient is received by the infusion device **410** via the infusion tubing **440** and transmitted to the analyte monitoring unit **420** for further processing and analysis.

More specifically, referring to FIG. 4, the integrated infusion device and analyte monitoring system **400** includes a patch **450** provided with a cannula **470** and an analyte sensor **460**. The cannula **470** is configured to deliver or infuse medication such as insulin from the infusion device **410** to the patient. That is, in one embodiment, the cannula **470** and the analyte sensor **460** are configured to be positioned subcutaneous to the patient's skin. The analyte sensor **460** is configured to be positioned to be in fluid contact with the patient's analyte.

In this manner, the analyte sensor **460** is electrically coupled to integral wires provided within the infusion tubing **440** so as to provide signals corresponding to the measured or detected analyte levels of the patient to the infusion device **410**. In one embodiment, the infusion device **410** is

configured to perform data analysis and storage, such that the infusion device **410** may be configured to display the real time measured glucose levels to the patient on its display unit **411**. In addition to or alternatively, the infusion device **410** is configured to wirelessly transmit the received signals from the analyte sensor **460** to the analyte monitoring unit **420** for data analysis, display, and/or storage and the analyte monitoring unit **420** may be configured to remotely control the functions and features of the infusion device **410** providing additional user convenience and discreteness.

Referring back to FIG. 4, in one embodiment, the patch **450** may be configured to be substantially small without a transmitter unit mounted thereon, and provided with a relatively small surface area to be attached to the patient's skin. In this manner, the patient may be provided with added comfort in having a substantially compact housing mounted on the skin (attached with an adhesive layer, for example), to infuse medication such as insulin, and for continuous analyte monitoring with the analyte sensor **460**.

FIG. 5 illustrates an integrated infusion device and analyte monitoring system in accordance with still a further embodiment of the present disclosure. As compared with the embodiment shown in FIG. 4, the integrated infusion device and analyte monitoring system **500** of FIG. 5 includes an integrated infusion device and analyte monitoring unit **510**. Accordingly, one user interface is provided to the user including the display unit **511** and input buttons **512** provided on the housing of the integrated infusion device and analyte monitoring unit **510**. Also shown in FIG. 5 are infusion tubing **520** with integral wires disposed therein and connected to analyte sensor **540** electrodes in fluid contact with the patient's analyte. Moreover, as can be seen from FIG. 5, an adhesive patch **530** is provided to retain the subcutaneous position of a cannula **550** and the analyte sensor **540** in the desired positions under the patient's skin.

Optionally, the integrated infusion device and analyte monitoring unit **510** may be provided with wireless or wired communication capability to communicate with a remote terminal such as a physician's computer terminal over a wireless communication path such as an RF communication link, or over a cable connection such as a USB connection, for example. Referring back to FIG. 5, in one embodiment of the present disclosure, the diabetic patient using an infusion therapy is provided with fewer components to handle or manipulate further simplifying insulin therapy and glucose level monitoring and management.

FIG. 6 illustrates an integrated infusion device and monitoring system in accordance with yet still a further embodiment of the present disclosure. Referring to FIG. 6, the integrated infusion device and analyte monitoring system **600** is provided with an infusion device without a user interface, and configured to wirelessly communicate with an analyte monitoring unit **620** over a communication path **630** such as an RF link. The infusion device **610**, which may be provided in a compact housing since it does not incorporate the components associated with a user interface, is connected to an infusion tubing **640** having disposed therein integral wires correspondingly connected to the electrodes of analyte sensor **660** in fluid contact with the patient's analyte. In addition, the compact adhesive patch **650** in one embodiment is configured to retain cannula **670** and the analyte sensor **660** in the desired position under the skin of the patient.

Similar to the embodiment shown in FIG. 3, the analyte monitoring unit **620** is configured to control and program the infusion device **610** over the communication link **630**. In this manner, the control and programming functions of the



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infusion device **610** may be remotely performed by the analyte monitoring unit **620**, providing convenience to the patient.

FIG. 7A illustrates the integrated infusion device and monitoring system shown in FIG. 6 in further detail in one embodiment of the present disclosure, while FIGS. 7B-7C illustrate the analog front end circuitry located at the patient interface and the pump assembly, respectively, of the integrated infusion device and monitoring system shown in FIG. 7A in accordance with one embodiment of the present disclosure. Referring to FIG. 7A, an infusion device **710** connected to an infusion tubing **720** with integral wires provided therein for connection to the electrodes of the analyte sensor is shown. The infusion tubing **720** is further connected to an adhesive patch **730** which is configured to retain cannula **750** and analyte sensor **740** in the desired subcutaneous position under the skin of the patient.

Referring to FIG. 7A, in one embodiment of the present disclosure, the infusion device **710** may be provided with a first analog front end circuitry unit **711**, while the adhesive patch may be provided with a second analog front end circuitry unit **731**. The integral wires from the analyte sensor **740** are configured to extend from the infusion device **710** to the adhesive patch **730** via the infusion tubing **720**. Since the analyte sensor **740** in one embodiment is a passive component, the signals on the working electrode and the reference electrodes of the analyte sensors are subject to noise given the high impedance of the electrodes and the length of the integral wires (in excess of a few centimeters). The noise in turn may potentially adversely affect the signals on the working and reference electrodes, which may distort the measured analyte levels detected by the analyte sensor **740**.

Given the length of the integral wire which corresponds to the length of the infusion tubing **720**, in one embodiment, the signals from the working and reference electrodes may be converted to low impedance signals to minimize adverse impact from the noise. Accordingly, the infusion device **710** may be provided with a first analog front end circuitry unit **711**, while the adhesive patch **730** may be provided with a second analog front end circuitry unit **731** as discussed in further detail below in conjunction with FIGS. 7B and 7C.

Referring now to FIG. 7B, the second analog front end circuitry unit **731** disposed on the adhesive patch **730** on the patient's skin, in one embodiment includes a trans-impedance amplifier (current to voltage converter or "I-to-V") **731A** configured to convert the working electrode (W) current to a voltage ( $V_w$ ), and to provide a guard signal (G), and a servo segment **731B** to drive the counter electrode (C) voltage ( $V_c$ ) based on the reference electrode (R) voltage. Also shown in FIG. 7B is a Low-Pass Filter (LPF) and gain stage **711A** that follow each of the I-to-V and servo stages, and which is configured in one embodiment to drive an A/D (Analog-to-Digital) converter unit **711C** whose results are read by a controller such as a central processing unit (CPU) **711D**. The A/D converter unit **711C** and the CPU **711D** and other peripherals may be combined into a single integrated circuit (IC) known as a microcontroller ( $\mu C$ ) such as the MSP430 product line.

Referring now to FIG. 7C, in one embodiment, the second analog front end circuitry unit **731** may be implemented by a pair of operational amplifiers (**731A** and **731B**), four resistors ( $R_1$ ,  $R_2$ ,  $R_3$ ,  $R_F$ ), and a bypass capacitor ( $C_b$ ). The I-to-F stage using operational amplifier **731A** is generated by the action of the input current from the working electrode (W) flowing through the feedback resistor ( $R_F$ ) and creating a voltage differential that is driven by the operational amplifier **731A** as the low impedance signal  $V_w$ . The offset for the

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$V_w$  signal is established by the resistor divider comprised of  $R_1$ ,  $R_2$  and  $R_3$ , which also creates the voltage of the guard signal (G)—a signal that is at the same potential or voltage as the working electrode (W).

The servo, using operational amplifier **731B**, in one embodiment, drives the counter electrode (C) voltage to the sensor so that the reference electrode (R) is at the second value set by the resistor divider comprised of resistors  $R_1$ ,  $R_2$  and  $R_3$ . This maintains the working electrode (W) voltage above the reference electrode (R) by a set amount known as the "Poise Voltage" (i.e. 40 mV). The bypass capacitor ( $C_b$ ) may be a small, low equivalent series resistance (ESR) capacitor, such as a 0.1  $\mu F$  (100 nF) multi-layer ceramic (MLC) capacitor, that acts to provide local energy and reduce noise on the circuit. The voltage source for this circuit may be provided by the potential difference between  $V_+$  and  $V_-$  where, for example,  $V_+$  may be 5V and  $V_-$  may be ground (GND) or  $V_+$  may be +3V and  $V_-$  may be -3V.

In one embodiment, the operational amplifiers **731A**, **731B** may be acquired as a dual operational amplifier integrated circuit (IC) in a single, small 8-pin, surface mount technology (SMT) package such as the OPA2349 in a SOT23-8 package (3 mm by 3 mm). Similar dual operational amplifier products may be available in even smaller ball-grid array (BGA) packages and as bare die that may be mounted directly to the circuit substrate, such as a printed circuit board (PCB) or flex circuit, using techniques such as "flip-chip" and wire-bond.

In one aspect, the analyte sensor described above in conjunction with the Figures may include one or more working electrodes and a reference electrode or a reference/counter electrode disposed on a substrate, and further, may optionally include a separate counter electrode. Indeed, in one aspect, the various electrodes of the sensor as well as the substrate and the dielectric layers may be provided in a stacked, side by side, or layered configuration or construction. For example, in one aspect, the sensor may include a substrate layer and a first conducting layer such as a carbon trace disposed on at least a portion of the substrate layer, and which may comprise the working electrode. Also shown disposed on at least a portion of the first conducting layer is a sensing layer.

A first insulation layer such as a first dielectric layer may be disposed or stacked on at least a portion of the first conducting layer, and further, a second conducting layer such as another carbon trace may be disposed or stacked on top of at least a portion of the first insulation layer (or dielectric layer). The second conducting layer may comprise the reference electrode, and in one aspect, may include a layer of silver/silver chloride (Ag/AgCl).

Further, a second insulation layer such as a dielectric layer in one embodiment may be disposed or stacked on at least a portion of the second conducting layer. Further, a third conducting layer, which may include carbon trace and that may comprise the counter electrode, may be disposed on at least a portion of the second insulation layer. Finally, a third insulation layer may be disposed or stacked on at least a portion of the third conducting layer. In this manner, the analyte sensor may be configured in a stacked, side by side or layered construction or configuration such that at least a portion of each of the conducting layers is separated by a respective insulation layer (for example, a dielectric layer).

Additionally, within the scope of the present disclosure, some or all of the electrodes of the analyte sensor may be provided on the same side of the substrate in a stacked construction as described above, or alternatively, may be provided in a co-planar manner such that each electrode is



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disposed on the same plane on the substrate, however, with a dielectric material or insulation material disposed between the conducting layers/electrodes. Furthermore, in still another aspect, the one or more conducting layers such as the electrodes of the sensor may be disposed on opposing sides of the substrate.

Referring again to the Figures, FIGS. 8A-8C illustrate a passive sensor configuration for use in a continuous analyte monitoring system, and two embodiments of an active sensor configuration for use at the patient interface in the integrated infusion device and monitoring system, respectively, in accordance with one embodiment of the present disclosure. Referring to FIG. 8A, analyte sensor 810 includes working electrode 811, a guard trace 812, a reference electrode 813, and a counter electrode 814. In one embodiment, the "tail" segment 815 of the analyte sensor 810 is configured to be positioned subcutaneously under the patient's skin so as to be in fluid contact with the patient.

Referring now to FIG. 8B, analyte sensor 820 is provided with the analog front end portion 821 where the four contacts shown are V+, V-, Vw, and Vc signals in accordance with one embodiment in place of the working electrode 811, a guard trace 812, a reference electrode 813, and a counter electrode 814, respectively. In this manner, in one embodiment of the present disclosure, these signals of the active analyte sensor 820 are low impedance and thus less subject to noise than the passive sensor signals. Moreover, in one embodiment, the analyte sensor 820 configuration may include a flex circuit.

Referring now to FIG. 8C, in a further embodiment, an active sensor of similar construction to the active sensor 820 of FIG. 8B but with much smaller dimensions is shown. More specifically, analyte sensor 830 is provided with four contacts configured for direct wire bonding rather than a mechanical contact system as indicated by the large contact areas on the previous two sensor configurations shown in FIGS. 8A-8B. Since the shape of the analyte sensor 830 is reduced, the sensor 830 may be wrapped around the cannula (for example, cannula 470 of FIG. 4) and thus only a single entry site may be required for the patient analyte monitoring and insulin infusion. Moreover, within the scope of the present disclosure, additional sensor/cannula configurations may be provided where the sensor circuitry and cannula are created as a single assembly such as a cannula with the circuit 831 fabricated on the surface.

FIG. 9 illustrates an integrated infusion device and analyte monitoring system with the infusion device and the monitoring system transmitter integrated into a single patch worn by the patient in accordance with one embodiment of the present disclosure. Referring to FIG. 9, the integrated infusion device and analyte monitoring system 900 includes an integrated patch pump and transmitter unit 910 provided on an adhesive layer 960, and which is configured to be placed on the skin of the patient, so as to securely position cannula 950 and analyte sensor 940 subcutaneously under the skin of the patient. The housing of the integrated infusion pump and transmitter unit 910 is configured in one embodiment to include the infusion mechanism to deliver medication such as insulin to the patient via the cannula 950.

In addition, the integrated patch pump and transmitter unit 910 is configured to transmit signals associated with the detected analyte levels measured by the analyte sensor 940, over a wireless communication path 930 such as an RF link. The signals are transmitted from the on body integrated patch pump and transmitter unit 910 to a controller unit 920 which is configured to control the operation of the integrated patch pump and transmitter unit 910, as well as to receive the

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transmitted signals from the integrated patch pump and transmitter unit 910 which correspond to the detected analyte levels of the patient.

Referring back to FIG. 9, in one embodiment, the infusion mechanism of the integrated patch pump and transmitter unit 910 may include the infusion device of the type described in U.S. Pat. No. 6,916,159 assigned to the assignee of the present disclosure Abbott Diabetes Care Inc. In addition, while a wireless communication over the communication path 930 is shown in FIG. 9, the wireless communication path 930 may be replaced by a set of wires to provide a wired connection to the controller unit 920.

In this manner, in one embodiment of the present disclosure, the integrated infusion device and analyte monitoring system 900 does not use an infusion tubing, which may provide additional comfort and convenience to the patient by providing additional freedom from having to wear a cumbersome tubing.

FIG. 10 is a detailed view of the infusion device cannula integrated with analyte monitoring system sensor electrodes in accordance with one embodiment of the present disclosure. Referring to FIG. 10, there is shown an infusion device cannula with analyte sensor electrodes 1020 disposed therein, and mounted to an adhesive patch 1010 so as to retain its position securely in the patient. More specifically, as can be seen from FIG. 10, the cannula with analyte sensor electrodes 1020 include sensor electrodes 1021, 1022, 1023 (which may correspond to working, reference and counter electrodes, respectively) each of which are provided within the cannula tip 1020, and further, positioned so as to maintain fluid contact with the patient's analyte. In one aspect, some or all of the electrodes of the analyte sensor may be wrapped around the cannula, stacked on one or more inner and/or outer surfaces of the cannula.

FIGS. 12A-12C each illustrate a cross sectional view of the infusion device cannula integrated with continuous analyte monitoring system sensor electrodes of FIG. 10 in accordance with the various embodiments respectively, of the present disclosure. Referring to FIG. 12A, in one embodiment, the cannula 1220 and sensor tubing 1228 are provided in parallel. More specifically, it can be seen from the Figure that cannula tubing wall 1220 provides a tube bore 1224 for insulin flow, and that each of the three insulated wires are provided with an outer casing or insulation layer 1225 of tubing wall individually surrounding each insulated wire 1221, 1222, 1223 and further, where the three insulated wires 1221, 1222, 1223 are in turn surrounded by the sensor tubing wall 1228.

Referring now to FIG. 12B in one embodiment of the present disclosure, the insulated wires 1221, 1222, 1223 respectively connected to the sensor electrodes are co-extruded into tubing wall 1220, with the tube bore 1224 for insulin delivery and the insulated wires 1221, 1222, 1223 configured substantially as shown in the FIG. 12B. Referring now to FIG. 12C, in still a further embodiment of the present disclosure, each of the insulated wires 1221, 1222, 1223 (each insulated by an insulation layer 1225) are wrapped around the tubing 1220 and covered with a sheath 1210, thus providing the tubing wall 1220, the tubing bore 1224 for insulin delivery, the individual insulated wires 1221, 1222, 1223, and the outer protective sheath 1210, which may also serve as an electromagnetic shield to eliminate electronic noise as substantially shown in the Figure.

Referring again to the Figures, the embodiments shown in FIGS. 12A and 12C may have a larger cross-sectional area (thus a larger hole needed to be punctured on the skin of the patient), but are likely easier to manufacture, more reliable



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and easier to make connection to the analyte sensor electronics). Additionally, within the scope of the present disclosure, an optical data transmission (i.e. fiber optics) along insulin delivery tubing between sensor and pump may be provided instead of integral wires as discussed above.

FIG. 11A illustrates a component perspective view of the infusion device cannula integrated with analyte monitoring system sensor electrodes in accordance with another embodiment of the present disclosure, while FIG. 11B illustrates a top planar view of the analyte monitoring system transmitter unit integrated with infusion device in accordance with one embodiment of the present disclosure. Referring to FIGS. 11A-11B, in one embodiment of the present disclosure, integrated analyte sensor and infusion device cannula 1100 comprises five laminated layers including a top insulation layer 1101, a conductive layer 1102 with electrode traces disposed thereon, followed by three layer substrate with integrated infusion cannula 1103.

In one embodiment, the three layer substrate with integrated infusion cannula 1103 includes a separation/insulation layer 1103A to insulate the sensor electrodes from the infusion cannula, a channel layer 1103B configured to guide the flow of the insulin or any other suitable medication, and an inlet/outlet layer 1103C. Also shown in FIG. 11A is an assembled view of the integrated analyte sensor and infusion device cannula 1100.

Referring now to FIG. 11B, it can be seen that a patch pump as shown in one embodiment is provided with a transmitter unit 1110 and an insulin pump 1130 coupled to insulin reservoir 1120, and operatively coupled or mounted to the transmitter unit 1110. Also shown in FIG. 11B are the analyte sensor contacts 1140 which are configured to establish electrical contact with the respective electrodes of the integrated infusion cannula and analyte sensor 1100. Also shown in FIG. 11B is insulin port 1150 which is connected to the channel layer 1103B of the integrated infusion device cannula and analyte sensor 1100.

In this manner, in one embodiment of the present disclosure, the patch pump may be worn by the patient on skin and which includes the insulin infusion mechanism as well as the analyte sensor and transmitter unit.

FIG. 13 is a timing chart for illustrating the temporal spacing of blood glucose measurement and insulin delivery by the integrated infusion device and monitoring system in one embodiment. More specifically, insulin pumps typically deliver insulin in a periodic manner with the period of delivery in the range of 2 to 3 minutes and the duration of delivery at each period being on the order of a few seconds or less. The amount of insulin that is delivered each period may be varied depending on the overall insulin delivery rate that is desired. The analyte data is collected continuously (as, for example, a continuous current of glucose oxidation) but is typically reported to the user periodically. The analyte reporting period is typically 1 to 10 minutes and glucose oxidation current needs to be collected for 10 to 30 seconds in order to generate a reportable glucose value (to allow for filtering etc.).

Indeed, the integration of analyte monitoring and insulin delivery may necessitate placement of an analyte sensor in close proximity to an insulin infusion cannula on the body. Such close proximity engenders the possibility of insulin delivery interfering with the analyte measurements. For example, if insulin infusion should result in a localized decrease in the glucose concentration in the area of the body near the infusion site, then glucose measurement in this area would not be representative of the glucose concentration in the body as a whole. Accordingly, in one embodiment of the

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present disclosure, there is provided a method for temporal spacing of blood glucose measurements and insulin delivery to mitigate the possible interference between insulin infusion and glucose measurements.

In accordance with one embodiment, the temporal spacing of analyte measurement and insulin delivery may include providing a large temporal space from after insulin delivery and before taking an analyte measurement. Since both analyte measurement and insulin delivery are performed periodically, a maximum spacing in time may be achieved if analyte measurement substantially immediately precedes insulin delivery. During the time between insulin delivery and the subsequent glucose measurement, infused insulin has time to diffuse and be transported away from the infusion site due to normal circulation of interstitial fluid. An example timeline of temporally spaced analyte measurement and insulin delivery is shown in FIG. 13. If multiple analyte measurements are taken between insulin delivery points, there should always be a reading just prior to insulin delivery and as well as just after insulin delivery to minimize the effect of injected insulin on the glucose measurement readings.

Although readings are typically taken periodically for simplicity in processing, a reading may be taken out of time with other readings and scaled appropriately for the overall reading average. Similarly, the insulin delivery point may be delayed slightly until after the reading with little or no affect as the readings typically occur much more frequently than the infusions, which are intended to act over longer periods of time. In addition, other timing considerations may be considered depending on the environment in which the integrated infusion device and analyte monitoring system is used by the patient, within the scope of the present disclosure to minimize potential error on measured analyte levels and/or introduce noise or potential adverse effects to the infusion rates of the infusion device.

More specifically, fluctuation in the power supplies of the infusion device and/or the analyte monitoring system, including, for example, batteries or related power distribution circuitry, may introduce electrical noise effects, which may adversely affect the measured readings associated with the analyte monitoring system. For example, when the analyte monitoring system is configured to be in an active state so as to be transmitting or receiving data, or when the pump cycle of the infusion device is active, the power supply may be affected by the load from the data transmission/reception, or the pumping cycle. The adverse effect of the power supply in addition to noise from other components of the electronic circuitry may introduce undesirable noise and adversely affect the accuracy of the analyte sensor measurements.

Accordingly, the transmitter unit 150 (FIG. 1) for example, may be configured to monitor the timing or occurrence of the measured analyte level received from the analyte sensor 160 and the data transmission timing of the transmitter unit 150 such that the two events do not substantially overlap or occur at substantially the same time. Alternatively, the analyte monitor unit 120 (FIG. 1) may be configured to compare the timing of the analyte sensor 160 measurement and the timing of the data transmission from the transmitter unit 150, and to discard data analyte related data received from the transmitter unit 150 which coincide with the timing of the analyte measurements by the analyte sensor 160.

Moreover in one embodiment, air bubble detection in the insulin tubing may be provided, by monitoring fluid motion that would also detect the absence of fluid such as that due



to an air bubble in the line. In one embodiment, the flow sensor may be configured to generate zero current when an air bubble is present.

In addition, colorization of insulin may be provided for air bubble detection in the tubing. Since pharmaceutical insulin is a clear colorless liquid, it is difficult to visually discriminate between insulin and air in tubing that carries insulin from the insulin pump to the cannula. By providing a color tint to the insulin it would be much easier to visually identify air bubbles in the tubing and be able to remove them before they cause problems. An insulin tint in one embodiment is biocompatible and insulin compatible.

In certain embodiments, the various components of the integrated system, for example, of the infusion device and analyte monitoring system **100** (FIG. **1**) may need periodic replacement, where the components may require replacement at different times during the usage of the integrated system. For example, the infusion device cannula may require replacement after about each 3-days of usage, while the analyte sensor for use in the analyte monitoring system may not require replacement until at least about five or seven days of usage. Accordingly, in one embodiment, the components of the integrated system may be provided as replaceable modular components such that one or more components may be replaced at different times during the usage of the integrated system without substantially impacting the remaining portion of the integrated system.

More particularly, FIGS. **14A-14C** illustrate modular combination of medication delivery and physiological condition monitoring system in accordance with one embodiment. Referring to FIGS. **14A-14C**, an on-body patch pump housing **1401** may be provided on the skin surface **1404** of the patient, such that the cannula **1402** is positioned transcutaneously through the patient's skin surface **1404** into the patient's body. Further shown is a connection port **1403** provided on the housing **1401** of the patch pump. As discussed in further detail below, the connection port **1403** in one embodiment may be configured to couple to an end cap **1405** (FIG. **14B**) if the patch pump is used as a pump alone, or alternatively may be configured to couple to an analyte sensor connector portion **1406** when used as an integrated system with an analyte monitoring system.

Referring to the Figures, as can be seen, the analyte sensor may include a connector portion **1406**, which is configured to couple to the connection port **1403** of the patch pump housing to establish a substantially water tight seal, an anchor portion **1407**, which is configured to securely position the analyte sensor on the skin surface **1404** of the patient, and the tip portion **1408**, which is transcutaneously positioned through the skin surface **1404** of the patient so as to be in fluid contact with the patient's analyte.

In this manner, in one embodiment, the analyte sensor may be provided as a modular component, which may be used in conjunction with the patch pump as an integrated system. Alternatively, as discussed above, the patient may select to use the patch pump alone without the continuous monitoring aspect of the integrated system. In this case, the modular system described herein may be easily used as a stand alone pump, where the end cap may be configured to provide a substantially water tight seal to the housing **1401** of the patch pump.

Alternatively, the patch pump may be used in conjunction with the analyte monitoring system wherein the patch pump housing **1401** may be configured to couple to the sensor connector portion **1406**, establishing electrical contact between the sensor electrodes to the respective internal electronic components within the patch pump housing **1401**.

In this case, the electronic components associated with the analyte monitoring system, including the transmitter unit, processing unit and other components of analyte monitoring system may be provided substantially within the housing of the patch pump **1401**.

In this manner, in certain aspects of the present disclosure, the integrated system may be used as a standalone infusion device, the patch pump and the analyte sensor may be replaced or changed independent of each other, and without substantially increasing the profile or the on-body size of the overall system, the sensor may be inserted or positioned in the patient independent of the patch pump, and also removed independent of the pump housing **1401**.

FIGS. **15A-15C** illustrate modular combination of medication delivery and physiological condition monitoring system in accordance with another embodiment. Referring to the Figures, similar to the embodiment shown in FIGS. **14A-14C**, the integrated system is provided with a patch pump housing **1501** which is configured for positioning on the skin surface **1504** of the patient, and which is operatively coupled to a transcutaneously positioned cannula **1502** for medication delivery to the patient.

In the embodiment shown in FIGS. **15A-15C**, the connection port **1503** of the patch pump is provided substantially on the top surface of the pump housing **1501**, such that, when desired, the analyte sensor connector portion **1506** may be coupled to the patch pump via the connection port **1503** from the top surface of the patch pump. Alternatively, as shown in FIG. **15B**, in one aspect, a cap or a plug **1505** may be provided to seal (for example, water tight seal) the connection port **1503** when the patch pump housing **1501** is not connected to an analyte sensor, and thus for use as a stand alone infusion device. In one aspect, the cap or plug **1505** may include any suitable configuration, preferably to include a low profile physical dimension so as to maintain the low profile configuration of the on-body patch pump housing **1501**.

As before, in particular embodiments, the connection port **1503** is configured to establish electrical connect with the various electrodes of the analyte sensor while providing a water tight seal at the connection. Referring again to the Figures, the analyte sensor includes an anchor portion **1507** configured to securely position the sensor on the skin surface **1504** of the patient, and a tip portion **1508** which is configured for transcutaneous placement for fluid contact with the patient's analyte.

While the embodiments described above include connection port of the patch pump housing provided on an end surface or a top surface of the pump housing, within the scope of the present disclosure, the connection port of the patch pump may be provided on any location of the patch pump housing. For example, within the scope of the present disclosure, the connection port providing a water tight seal when connected with an end cap (to establish closure), or with an analyte sensor (to use the patch pump in an integrated system with analyte monitoring), may be provided on the bottom, side, or any other surface of the patch pump housing.

FIG. **16** illustrates a top planar view of a modular sensor component in accordance with one embodiment. More particularly, FIG. **16** illustrates the analyte sensor of FIGS. **14A-14C** or **15A-15C** in one embodiment. As shown, the connector portion **1606** of the analyte sensor is provided substantially on one end of the analyte sensor, while the sensing portion **1608** (for transcutaneous placement) of the analyte sensor is provided substantially on the other end of the sensor. Also shown in FIG. **16** is the anchor portion **1607**,



which, in one embodiment, is configured with a relatively larger width compared to other portions of the sensor.

In this manner, the anchor portion **1607** may be configured to substantially securely retain the analyte sensor on the skin surface of patient. Furthermore, one or more of the patch pump housing and the analyte sensor may be provided with an adhesive layer on the bottom surface to secure positioning on the patient's skin surface during usage. In a further aspect, the analyte sensor may comprise a flex circuit so as to provide a low profile when worn on the body of the patient.

FIG. 17 illustrates modular combination of medication delivery and physiological condition monitoring system in accordance with yet another embodiment. Referring to FIG. 17, the patch pump **1701** is provided with a connection port **1703** and positioned on the patient's skin surface **1704** so as to securely retain the transcutaneously positioned cannula **1702** at the desired depth under the skin layer of the patient. Also shown in the Figure is a connection device **1706** which, in one embodiment, is provided with a pump connector **1705** and a sensor connector **1707**. More specifically, in one embodiment, a separate modular component is provided and secured on the skin surface **1704** of the patient, and may be configured to connect to both the patch pump **1701** as well as the analyte sensor. Moreover, within the scope of the present disclosure, the connection device **1706** may be configured to further couple to other components or devices as may be desired.

Referring back to FIG. 17, in one aspect, the connection device **1706** is configured to establish electrical connection between the sensor and the patch pump such that the detected analyte levels from the tip portion **1710** of the analyte sensor is received by the suitable electronic control circuitry within the patch pump housing **1701**. In an alternate embodiment, the analyte monitoring associated electronic components such as data processing units, transmitter units, and the like, may be provided within the connection device **1706**. In this case, the patch pump housing **1701** may be further optimized in size.

Referring yet again to FIG. 17, the connection device **1706** is configured in one embodiment to include the pump connector **1705**, which, in one embodiment, is configured to couple to the connection port **1703** of the pump to establish electrical contact and a substantially water tight seal. Furthermore, the connection device **1706** may be further configured to include a sensor connector portion **1707**, which is configured to receive or connect to the connector portion **1708** of the sensor so as to establish electrical contact with the various electrodes of the sensor. That is, in one embodiment, the connector portion **1707** of the connection device **1706** may be configured to couple to the sensor connector portion **1708**. Accordingly, when the sensor tip **1710** is inserted through the skin surface **1704** of the patient and in fluid contact with the patient's analytes, and retained securely in place by the adhesive tab portion **1709**, the sensor connection portion **1708** is configured in one embodiment to establish electrical contact with the connection device **1706** to transfer or otherwise relay the signal level information associated with the detected analyte levels of the patient for further processing.

In this manner, in one aspect of the present disclosure, there are provided modular components or devices which comprise an integrated medication delivery and analyte monitoring system, where each component may be independently replaced, removed, or used on its own, and further,

where the modular components may be used together as an integrated system for medication delivery and analyte monitoring.

Accordingly, a modular system for providing integrated medication delivery and physiological condition monitoring in one aspect includes a first modular component configured for medication delivery, and a second modular component configured to analyte level detection, where the second modular component is connectable to the first modular component to establish electrical contact with the first modular component, where a substantially water tight seal is formed when the first and second modular component are connected, and further where one of the first modular component and the second modular component is configured for replacement independent of the other component, and a third modular component connectable to the first modular component when the first modular component is disconnected with the second modular component.

In one aspect, the first modular component may include a connection port for coupling to either one of the second modular component or the third modular component.

The first modular component may include a low profile infusion device.

The second modular component may include an analyte sensor.

Further, in one aspect, a water tight seal may be formed when the first and third modular components are connected.

The first modular component in still another aspect may be configured to deliver medication to a patient at a first location in the patient, and further, wherein the second modular component is configured to detect analyte level of the patient at a second location in the patient, where the first and second locations may be separated by a predetermined distance, for example, approximately 12 inches.

The first modular component in another aspect may include a reusable portion and a disposable portion, where either of the second or third modular components is connectable to the reusable portion of the first modular component.

The disposable portion of the first modular component may include one or more of an infusion set, or a reservoir containing the medication for delivery.

The reusable portion of the first modular component may include a processing unit to control the operation of one or more of the first modular component or the second modular component.

In yet still another aspect, the system may include a communication unit disposed in one or more of the first modular component or the second modular component, the communication unit configured to transmit to or receive data from a remote location.

The remote location may include one or more of a portable control unit, a computer terminal, a server terminal, a mobile telephone, or a personal digital assistant.

The communication unit may be configured to transmit one or more signals corresponding to a respective one or more analyte levels to the remote location.

In another aspect, the communication unit may be configured to receive a flow instruction command to control delivery of the medication.

Further, in still another aspect, the communication unit may be configured to wirelessly communicate over one or more of an RF communication link, a Bluetooth® communication link, or an infrared communication link.

The second modular component in a further aspect may include an inner wall and an outer wall, a plurality of electrodes disposed between the inner wall and the outer



wall, and a fluid delivery channel formed by the inner wall, where the plurality of electrodes may include an analyte sensor.

A method in accordance with another embodiment may include providing a first modular component for medication delivery, providing a second modular component configured to analyte level detection, the second modular component connectable to the first modular component to establish electrical contact with the first modular component, forming a substantially water tight seal when the first and second modular components are connected, and providing a third modular component connectable to the first modular component when the first modular component is disconnected with the second modular component, where one of the first modular component and the second modular components are configured for replacement independent of the other component.

In another aspect, the method may include delivering medication to a patient, and monitoring analyte level of the patient substantially concurrently to the medication delivery.

A modular system for providing integrated medication delivery and physiological condition monitoring in accordance with still another aspect includes a replaceable first modular component configured to deliver medication, a replaceable second modular component configured to analyte level detection, where the second modular component is connectable to the first modular component to establish electrical contact with the first modular component, and a third modular component connectable to the first modular component when the first modular component is disconnected from the second modular component, where a substantially water tight seal is formed when the first and second modular components are connected or when the first and third modular components are connected.

The one of the first modular component and the second modular components may be configured for replacement independent of the other component.

The first modular component may include a connection port to couple to either one of the second modular component or the third modular component, and further, where the third modular component may include a cap configured to couple to the connection port of the first modular component.

The cap may include an end cap or a plug.

The analyte level monitored may include glucose level.

The first modular component may include a low profile infusion device.

The second modular component may include an analyte sensor.

The first modular component may be configured to deliver medication to a patient at a first location in the patient, and further, where the second modular component may be configured to detect analyte level of the patient at a second location in the patient.

In yet a further aspect, the first and second locations are separated by a predetermined distance.

The first modular component may include a reusable portion and a disposable portion, where either of the second or third modular components are connectable to the reusable portion of the first modular component.

The disposable portion of the first modular component may include one or more of an infusion set, or a reservoir containing the medication for delivery.

The reusable portion of the first modular component may include a processing unit to control the operation of one or more of the first modular component or the second modular component.

Also the system may include a communication unit disposed in one or more of the first modular component or the second modular component, the communication unit configured to transmit to or receive data from a remote location, and further, where the remote location may include one or more of a portable control unit, a computer terminal, a server terminal, a mobile telephone, or a personal digital assistant.

The communication unit may be configured to transmit one or more signals corresponding to a respective one or more analyte levels to the remote location.

Also, the communication unit may be configured to receive a flow instruction command to control delivery of the medication.

The communication unit may be configured to wirelessly communicate over one or more of an RF communication link, a Bluetooth® communication link, or an infrared communication link.

In still yet another aspect, the second modular component may include an inner wall and an outer wall, a plurality of electrodes disposed between the inner wall and the outer wall, and a fluid delivery channel formed by the inner wall.

The plurality of electrodes may comprise an analyte sensor.

A method in accordance with another aspect includes positioning a replaceable first modular component on a skin surface of a user, connecting a replaceable second modular component to a predetermined location on the first modular component during a first time period, wherein a water tight seal is formed between the first modular component and the second modular component, and connecting a third modular component to the predetermined location first modular component during a second time period, where a water tight seal is formed between the first modular component and the second modular component, and further where the first time period and the second time period are nonoverlapping.

The method may include delivering medication to the user, and monitoring analyte level of the user.

A kit in still another aspect may include an infusion device configured to deliver medication, the infusion device including a port, an analyte monitoring device configured to monitor an analyte level of a user, the analyte monitoring device connectable to the port of the infusion device during a first predetermined time period, and a cap connectable to the port of the infusion device during a second predetermined time period, where the first and second predetermined time periods are nonoverlapping.

The infusion device may include an on-body patch pump.

The cap provides a water tight seal on the port when connected to the infusion device.

The analyte monitoring device provides a water tight seal on the port when connected to the infusion device.

In still yet a further aspect, a system including an infusion device and an analyte monitoring unit includes an infusion device, an on-body unit including a data transmission section, the on-body unit further coupled to the infusion device, the on-body unit configured to receive one or more signals corresponding to a respective one or more analyte levels, and further, the on-body unit configured to infuse a fluid received from the infusion device, and a receiver unit operatively coupled to the on-body unit, the receiver unit configured to receive data from the on-body unit, wherein the received data is associated with the analyte level.

The system may further include an analyte sensor, at least a first portion of, which is in fluid contact with an analyte of a patient, and further, where, at a second portion of, the analyte sensor is in signal communication with the data transmission section.



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The data transmission section may, in one embodiment, be configured to transmit the one or more signals corresponding to a respective one or more analyte levels substantially periodically at one or more predetermined time intervals, where the one or more predetermined time intervals may include one or more of approximately 30 seconds, approximately one minute, or approximately 90 seconds.

In one aspect, the on-body unit may include a cannula, at least a portion of, which is subcutaneously positioned under a skin layer, and further, may also include an infusion tubing connected to the infusion device to deliver the fluid to the on-body unit. The infusion tubing and the on-body unit in a further aspect may be connected in a substantially water tight seal.

In yet another embodiment, the infusion tubing may be configured to operatively couple to the cannula to deliver the fluid.

The on-body unit may be configured to wirelessly transmit the one or more signals corresponding to the respective one or more analyte levels to the receiver unit, where the on-body unit and the receiver may be configured to wirelessly communicate over one or more of an RF communication link, a Bluetooth® communication link, or an infrared communication link.

In addition, the infusion device in a further embodiment may be configured to control the delivery rate of the fluid based on the one or more signals corresponding to the respective one or more analyte levels received by the receiver unit, and further, where the infusion device may be configured to determine a modified delivery protocol for delivering fluid such as insulin based on information associated with the one or more signals corresponding to the respective one or more analyte levels.

In yet another aspect, the modified delivery protocol may include one or more of a correction bolus, a modified basal profile, a carbohydrate bolus, an extended bolus, or combinations thereof.

The receiver unit in one embodiment may be configured to wirelessly communicate with the infusion device.

In a further embodiment, the receiver unit may be integrated into a housing of the infusion device.

A method of integrating analyte monitoring and fluid infusion in another embodiment of the present disclosure includes infusing a fluid at a predetermined delivery rate, detecting one or more analyte levels, transmitting one or more signals associated with the respective detected one or more analyte levels, and determining a modified delivery rate based on the transmitted one or more signals.

In one aspect, the one or more signals may be transmitted substantially immediately after the associated respective one or more analyte levels are detected.

Moreover, the transmitting step in one embodiment may include wirelessly transmitting the one or more signals which wirelessly transmitted over one or more of an RF communication link, a Bluetooth® communication link, an infrared communication link, or combinations thereof.

The method in a further aspect may also include the steps of receiving the transmitted one or more signals, and displaying the received one or more signals.

Moreover, the method may also include the step of displaying the modified delivery rate. In addition, the method may also include the step of implementing the modified delivery rate, where the predetermined delivery rate may include one or more basal delivery rates.

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The modified delivery rate in a further embodiment may include one or more of a correction bolus, a modified basal profile, a carbohydrate bolus, an extended bolus, or combinations thereof.

An apparatus including an analyte sensor and a fluid delivery channel in yet another embodiment of the present disclosure includes a fluid delivery unit having an inner wall and an outer wall, and a plurality of electrodes disposed between the inner wall and the outer wall of the fluid delivery unit, where a portion of the fluid delivery unit and a portion of the plurality of electrodes are subcutaneously positioned under a skin layer.

In one aspect, the plurality of electrodes may comprise an analyte sensor, including, for example, one or more of a working electrode, a counter electrode, a reference electrode, or combinations thereof.

The fluid delivery unit may include a channel for delivering a fluid such as insulin, the channel substantially formed by the inner wall.

An apparatus including an analyte sensor and a fluid delivery channel in accordance with still another embodiment of the present disclosure includes a first tubing having a first tubing channel, and a second tubing having a second tubing channel including a plurality of electrodes disposed within the second tubing channel, where at least a portion of the first tubing and at least a portion of the second tubing are subcutaneously positioned under a skin layer.

In one embodiment, the plurality of the electrodes may be substantially and entirely insulated from each other.

In another embodiment, the first tubing and the second tubing may be integrally formed such that an outer surface of the first tubing is substantially in contact with an outer surface of the second tubing.

A system including an infusion device and an analyte monitoring unit in accordance with still another embodiment of the present disclosure includes an infusion and monitoring device, an on-body unit including a data transmission section, the on-body unit further coupled to the infusion and monitoring device, the on-body unit configured to receive one or more signals corresponding to a respective one or more analyte levels, and further, the on-body unit configured to infuse a fluid received from the infusion and monitoring device, and a connector coupled at a first end to the infusion device, and further, coupled at a second end to the on-body unit, the connector configured to channel the fluid from the infusion device to the on-body unit, and further, configured to provide the one or more signals corresponding to the respective one or more analyte levels to the infusion and monitoring device.

In one aspect, the infusion and monitoring device may be configured to execute fluid delivery to a patient, and further, to detect analyte levels of the patient over a predetermined time period.

In a further aspect, the infusion and monitoring device may include a continuous glucose monitoring system.

In still another aspect, the infusion and monitoring device may include an insulin pump.

A method of fluid delivery and analyte monitoring in accordance with still another embodiment of the present disclosure includes determining a delivery profile for fluid infusion, wherein the delivery profile including a plurality of predetermined discrete fluid infusion each temporally separated by a predetermined time period, and sampling an analyte level substantially immediately prior to each predetermined discrete fluid infusion.



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The method may further include the step of sampling an analyte level substantially immediately after each predetermined discrete fluid infusion.

All references cited above herein, in addition to the background and summary sections, are hereby incorporated by reference into the detailed description of the preferred embodiments as disclosing alternative embodiments and components.

Various other modifications and alternations in the structure and method of operation of this invention will be apparent to those skilled in the art without departing from the scope and spirit of the invention. Although the invention has been described in connection with specific preferred embodiments, it should be understood that the invention as claimed should not be unduly limited to such specific embodiments.

What is claimed is:

1. A modular system for providing integrated medication delivery and analyte level monitoring, comprising:

a replaceable first modular component configured to deliver medication, the first modular component comprising a connection port and a processing unit;

a replaceable second modular component configured to monitor an analyte level with a sensor tip portion, wherein the second modular component is connectable to the connection port of the first modular component to establish electrical contact between the sensor tip portion and the processing unit of the first modular component such that a signal corresponding to the analyte level passes from the sensor tip portion, through the connection port, and is received at the processing unit; and

a third modular component connectable to the connection port of the first modular component only when the second modular component is disconnected from the connection port, wherein the first modular component is operable when the third modular component is connected to the connection port of the first modular component;

wherein a first substantially water tight seal is formed at the connection port when the first and second modular components are connected, or a second substantially water tight seal is formed at the connection port when the first and third modular components are connected, wherein the first modular component comprises a reusable portion and a disposable portion, the disposable portion including one or more of an infusion set or a reservoir containing the medication for delivery, and

wherein either of the second or third modular components are connectable to the reusable portion of the first modular component.

2. A modular system for providing integrated medication delivery and analyte level monitoring, comprising:

a replaceable first modular component configured to deliver medication, the first modular component comprising a connection port, a processing unit, and a tubular member configured to deliver medication at a first insertion site in a patient;

a replaceable second modular component comprising a sensor tip portion configured to detect an analyte level at a second insertion site in the patient, wherein the second modular component is connectable to the connection port of the first modular component to establish electrical contact between the sensor tip portion and the processing unit of the first modular component such that a signal corresponding to the analyte level passes

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from the sensor tip portion, through the connection port, and is received at the processing unit; and

a third modular component connectable to the connection port of the first modular component only when the second modular component is disconnected from the connection port, wherein the first modular component is operable when the third modular component is connected to the connection port of the first modular component;

wherein a first substantially water tight seal is formed at the connection port when the first and second modular components are connected, or a second substantially water tight seal is formed at the connection port when the first and third modular components are connected, and

wherein the first insertion site is associated with a first puncture and the second insertion site is associated with a second puncture different from the first puncture.

3. The system of claim 2, wherein one of the first modular component and the second modular component is configured for replacement independent of the other component.

4. The system of claim 2, wherein the third modular component includes a cap configured to couple to and directly contact the connection port of the first modular component.

5. The system of claim 2, wherein an analyte detected by the sensor tip is glucose.

6. The system of claim 2, wherein the first modular component includes a low profile medication infusion device.

7. The system of claim 2, wherein the first and second insertion sites are separated by a predetermined distance.

8. The system of claim 7, wherein the predetermined distance is less than approximately 12 inches.

9. The system of claim 2, wherein the first modular component includes a reusable portion and a disposable portion, wherein either of the second or third modular components are connectable to the reusable portion of the first modular component.

10. The system of claim 9, wherein the disposable portion of the first modular component includes one or more of an infusion set or a reservoir containing the medication for delivery.

11. The system of claim 9, wherein the processing unit is programmed to control the operation of one or more of the first modular component or the second modular component.

12. The system of claim 2, including a communication unit disposed in one or more of the first modular component or the second modular component, the communication unit configured to transmit to or receive data from a remote location.

13. The system of claim 12, wherein the remote location includes one or more of a portable control unit, a computer terminal, a server terminal, a mobile telephone, or a personal digital assistant.

14. The system of claim 12, wherein the communication unit is configured to wirelessly transmit data corresponding to the analyte level to the remote location.

15. The system of claim 12, wherein the communication unit is configured to receive a flow instruction command to control delivery of the medication.

16. The system of claim 2, wherein the connection port is located on one of a top surface or an end of the first modular component.

17. The system of claim 2, wherein the first modular component comprises a low profile configuration and the third modular component comprises a profile so as to



maintain the low profile configuration of the first modular component when the third modular component is connected to the connection port of the first modular component.

18. The system of claim 17, wherein the second modular component comprises a profile so as to maintain the low 5 profile configuration of the first modular component when the second modular component is connected to the connection port of the first modular component.

19. The system of claim 2, wherein the connection port comprises a receptacle configured for receiving a corresponding mating portion of the second modular component 10 and a corresponding mating portion of the third modular component, wherein the two corresponding mating portions have similar configurations.

20. The system of claim 2, wherein the processing unit is 15 within a housing of the first modular component, and wherein the first modular component includes an electronic pump controlled by the processing unit, wherein the electronic pump is also within the housing of the first modular component. 20

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