



(22) Date de dépôt/Filing Date: 2016/12/20

(41) Mise à la disp. pub./Open to Public Insp.: 2017/08/17

(45) Date de délivrance/Issue Date: 2023/08/22

(62) Demande originale/Original Application: 3 010 345

(30) Priorités/Priorities: 2016/02/12 (US62/294,973);  
2016/09/02 (US15/255,795)

(51) Cl.Int./Int.Cl. *E03B 9/06* (2006.01),  
*A62C 35/20* (2006.01), *A62C 37/50* (2006.01),  
*H01Q 1/42* (2006.01), *H01Q 1/44* (2006.01)

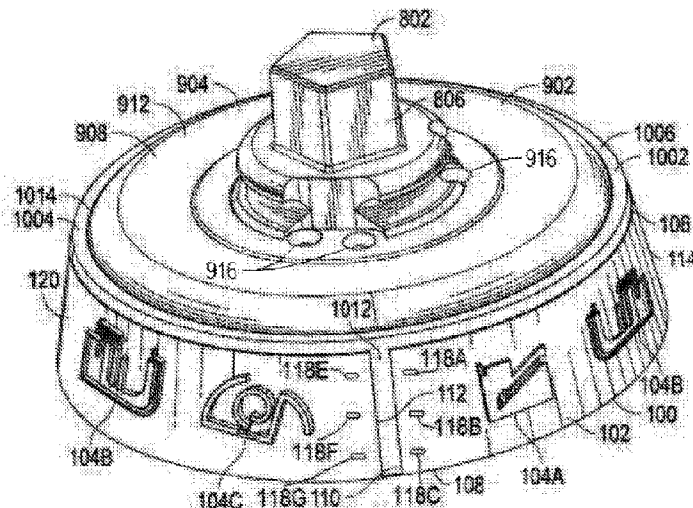
(72) Inventeurs/Inventors:  
GIBSON, DARYL LEE, US;  
ORTIZ, JORGE ISAAC, US;  
DUNN, DAVID JAMES CARLOS, CA;  
LI, YANLONG, US;  
FAUNCE, JESSE ALVIN, US

(73) Propriétaire/Owner:  
MUELLER INTERNATIONAL, LLC, US

(74) Agent: RIDOUT & MAYBEE LLP

(54) Titre : ENSEMBLE D'ANTENNE MULTIBANDE DE BOUCHON DE PRISE

(54) Title: NOZZLE CAP MULTI-BAND ANTENNA ASSEMBLY



(57) **Abrégé/Abstract:**

Nozzle cap assemblies and smart fluid system are disclosed. A nozzle cap assembly includes: a nozzle cap housing configured to mount on a hydrant, and defining an upper rim and a lower rim, an interior cavity extending inward from the upper rim toward the lower rim, an antenna mounting portion extending from the upper rim toward the lower rim; an antenna cover mounted on the nozzle cap housing, the antenna cover positioned over at least a portion of the antenna mounting portion, the antenna cover defining an inner cover surface facing the antenna mounting portion, an antenna cover cavity at least partially defined between the inner cover surface and the antenna mounting portion; and an antenna assembly positioned in the antenna cover cavity, the antenna assembly comprising a printed circuit board ("PCB") and an antenna structure positioned on the PCB, the PCB secured directly against the inner cover surface.

## **Abstract**

Nozzle cap assemblies and smart fluid system are disclosed. A nozzle cap assembly includes: a nozzle cap housing configured to mount on a hydrant, and defining an upper rim and a lower rim, an interior cavity extending inward from the upper rim toward the lower rim, an antenna mounting portion extending from the upper rim toward the lower rim; an antenna cover mounted on the nozzle cap housing, the antenna cover positioned over at least a portion of the antenna mounting portion, the antenna cover defining an inner cover surface facing the antenna mounting portion, an antenna cover cavity at least partially defined between the inner cover surface and the antenna mounting portion; and an antenna assembly positioned in the antenna cover cavity, the antenna assembly comprising a printed circuit board ("PCB") and an antenna structure positioned on the PCB, the PCB secured directly against the inner cover surface.

## NOZZLE CAP MULTI-BAND ANTENNA ASSEMBLY

### BACKGROUND

#### Field

**[0001]** This application relates to antenna assemblies for electromagnetic communication, and more particularly, to antenna assemblies for multi-band electromagnetic communication.

#### Background Technology

**[0002]** Wireless communication technology has advanced significantly over the past several years. A non-exhaustive list of examples of wireless communication systems includes radio broadcasting, television broadcasting, satellite television, two-way radio devices (e.g., CB radio, amateur radio, etc.), cellular phones, cordless phones, wireless local area networking, global positioning system (GPS) receivers, garage door openers, television remote control devices, and others. Each type of wireless communication system operates in specific frequency bands in compliance with various communication standards.

**[0003]** Some wireless communication devices are able to operate over two or more frequency bands to provide multiple services. However, many wireless devices operating in multiple bands include a single antenna, such that only one service can be provided at a time. Usually, conventional multi-band antennas are large and bulky, which prevents their application in many settings.

### SUMMARY

**[0004]** Described herein is a nozzle cap assembly. The nozzle cap assembly can be configured for mounting an antenna assembly. In one aspect, the nozzle cap assembly can comprise a nozzle cap housing configured to mount on a hydrant, a nozzle cap cover mounted on the nozzle cap housing, an antenna cover positioned on the nozzle cap housing and secured by the nozzle cap cover, the nozzle cap housing, the antenna cover, and the nozzle cap cover defining an antenna cover cavity, and an antenna assembly positioned in the antenna cover cavity.

**[0005]** In a further aspect, a method for monitoring for a parameter in a fluid system can comprise mounting a sensing node on the nozzle of a hydrant connected in fluid communication with the fluid system, the sensing node comprising a nozzle cap housing, a nozzle cap cover mounted on the nozzle cap housing, the nozzle cap cover and the nozzle cap housing defining an interior cavity, an antenna cover positioned on the nozzle cap housing and secured by the nozzle cap cover, the nozzle cap housing, the antenna cover, and the nozzle cap cover defining

an antenna cover cavity, a sensor mounted within the interior cavity and configured to collect data for the parameter, and an antenna assembly positioned in the antenna cover cavity and configured to transmit a signal carrying data gathered by the sensor, activating the sensing node, gathering data of the parameter with the sensor, and transmitting the data collected by the sensor with the antenna assembly.

**[0006]** In a further aspect, a smart fluid system can comprise a fluid system, a hydrant connected in fluid communication to the fluid system, the hydrant comprising a nozzle, a sensing node mounted on the nozzle of the hydrant, the sensing node comprising a nozzle cap housing, a nozzle cap cover attached to the nozzle cap housing, the nozzle cap cover and the nozzle cap housing defining an interior cavity, an antenna cover mounted on the nozzle cap housing and secured between the nozzle cap housing and the nozzle cap cover, the nozzle cap housing, the nozzle cap cover, and the antenna cover defining an antenna cover cavity, a sensor positioned within the interior cavity, the sensor configured to collect data for a parameter of the fluid system, and an antenna assembly mounted to the nozzle cap housing, the antenna assembly positioned within the antenna cover cavity, the antenna assembly configured to transmit the data collected by the sensor.

**[0006a]** In a further aspect, a nozzle cap assembly comprises: a nozzle cap housing configured to mount on a hydrant, the nozzle cap housing defining an upper rim and a lower rim, the nozzle cap housing defining an interior cavity extending inward from the upper rim toward the lower rim, the nozzle cap housing defining an antenna mounting portion extending from the upper rim toward the lower rim; an antenna cover mounted on the nozzle cap housing, the antenna cover positioned over at least a portion of the antenna mounting portion, the antenna cover defining an inner cover surface facing the antenna mounting portion, an antenna cover cavity at least partially defined between the inner cover surface and the antenna mounting portion; and an antenna assembly positioned in the antenna cover cavity, the antenna assembly comprising a printed circuit board ("PCB") and an antenna structure positioned on the PCB, the PCB secured directly against the inner cover surface.

**[0006b]** In a further aspect, a smart fluid system comprises: a fluid system; a hydrant connected in fluid communication to the fluid system, the hydrant comprising a nozzle; a sensing node mounted on the nozzle of the hydrant, the sensing node comprising: a nozzle cap housing defining an upper rim and a lower rim, the nozzle cap housing defining an interior cavity extending inward from the upper rim toward the lower rim, the nozzle cap housing defining an antenna mounting portion extending from the upper rim toward the lower rim; a sensor attached to the nozzle cap housing, the sensor configured to collect data for a parameter of the fluid

system; an antenna cover mounted on the nozzle cap housing, the antenna cover positioned over at least a portion of the antenna mounting portion, the antenna cover defining an inner cover surface facing the antenna mounting portion, an antenna cover cavity at least partially defined between the inner cover surface and the antenna mounting portion; and an antenna assembly positioned in the antenna cover cavity, the antenna assembly comprising a printed circuit board ("PCB") and an antenna structure positioned on the PCB, the PCB secured directly against the inner cover surface, the antenna assembly configured to transmit the data collected by the sensor.

**[0006c]** In a further aspect, a nozzle cap assembly comprises: a nozzle cap cover; a nozzle cap housing defining a first end and a second end, the first end positioned opposite from the second end, the nozzle cap housing comprising: an upper rim positioned at the first end, the nozzle cap cover mounted on the upper rim; a divider wall positioned between the first end and the second end, the nozzle cap housing defining an interior cavity extending into the upper rim to the divider wall, the interior cavity extending in a direction from the upper rim towards the second end, the nozzle cap cover enclosing the interior cavity; and a lower rim positioned at the second end, the nozzle cap housing defining an internally threaded bore extending into the lower rim to the divider wall, the internally threaded bore extending in a direction from the lower rim towards the first end, the divider wall positioned between the upper rim and the lower rim, the divider wall separating the interior cavity from the internally threaded bore, the internally threaded bore configured to mount on a nozzle of a fire hydrant; and an acoustic sensor positioned within the interior cavity between the divider wall and the upper rim, the acoustic sensor configured to detect vibrations.

**[0006d]** In a further aspect, a nozzle cap assembly comprises: a nozzle cap housing configured to mount on a hydrant, the nozzle cap housing defining an upper rim and a lower rim, the nozzle cap housing defining an interior cavity extending inward from the upper rim toward the lower rim, the nozzle cap housing defining an antenna mounting portion extending from the upper rim toward the lower rim; an antenna cover mounted on the nozzle cap housing, the antenna cover positioned over at least a portion of the antenna mounting portion, the antenna cover defining an inner cover surface facing the antenna mounting portion, an antenna cover cavity at least partially defined between the inner cover surface and the antenna mounting portion; an antenna assembly positioned in the antenna cover cavity, the antenna assembly secured in facing engagement with the inner cover surface; and potting positioned at least partially between the antenna cover and the interior cavity, the potting positioned at least partially between the antenna assembly and the interior cavity.

**[0007]** Various implementations described in the present disclosure can include additional systems, methods, features, and advantages, which can not necessarily be expressly disclosed herein but will be apparent to one of ordinary skill in the art upon examination of the following detailed description and accompanying drawings. It is intended that all such systems, methods, features, and advantages be included within the present disclosure and protected by the accompanying claims.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0008]** The features and components of the following figures are illustrated to emphasize the general principles of the present disclosure. Corresponding features and components throughout the figures can be designated by matching reference characters for the sake of consistency and clarity.

**[0009]** FIG. 1 is a top view of an antenna assembly according to one aspect of the present disclosure.

**[0010]** FIG. 2 is a top view of a base layer of the antenna assembly of FIG. 1.

**[0011]** FIG. 3 is a top view of a copper layer of the antenna assembly of FIG. 1.

**[0012]** FIG. 4 is a top view of a cover layer of the antenna assembly of FIG. 1.

**[0013]** FIG. 5 is a bottom view of the antenna assembly of FIG. 1.

**[0014]** FIG. 6 is a top view of an antenna assembly according to another aspect of the present disclosure.

**[0015]** FIG. 7 is a perspective view of an antenna assembly according to another aspect of the present disclosure.

**[0016]** FIG. 8 is a perspective view of a nozzle cap assembly including the antenna assembly of FIG. 1 according to another aspect of the present disclosure.

**[0017]** FIG. 9 is a perspective view of a nozzle cap of the nozzle cap assembly of FIG. 8.

**[0018]** FIG. 10 is a perspective view of a spacer of the nozzle cap assembly of FIG. 8.

**[0019]** FIG. 11 is a perspective view of the spacer of FIG. 10 mounted on the nozzle cap of FIG. 9.

**[0020]** FIG. 12 is another perspective view of the assembled spacer and nozzle cap of FIG. 11.

**[0021]** FIG. 13 is a perspective view of the antenna assembly of FIG. 1 mounted on the spacer and nozzle cap of FIG. 11.

**[0022]** FIG. 14 is an exploded view of a nozzle cap assembly including the antenna assembly of FIG. 6 according to another aspect of the present disclosure.

**[0023]** FIG. 15 is a perspective view of a nozzle cap of the nozzle cap assembly of FIG. 14.

**[0024]** FIG. 16 is a perspective view of an antenna cover and a mounting plate of the nozzle cap assembly of FIG. 14.

**[0025]** FIG. 17 is a perspective view of the antenna cover of FIG. 16.

**[0026]** FIG. 18 is a perspective view of the antenna assembly of FIG. 6 secured to the mounting plate of FIG. 16.

**[0027]** FIG. 19 is a perspective view of the antenna assembly of FIG. 6 secured to the mounting plate of FIG. 16 and positioned on the nozzle cap of FIG. 15.

**[0028]** FIG. 20 is a perspective view of the assembled nozzle cap assembly of FIG. 14.

**[0029]** FIG. 21 is a perspective view of the antenna of FIG. 7 positioned in the antenna cover of FIG. 14.

**[0030]** FIG. 22 is a perspective view of a nozzle cap assembly including the antenna assembly of FIG. 1 according to another aspect of the present disclosure.

**[0031]** FIG. 23 is a perspective view of a nozzle cap of the nozzle cap assembly of FIG. 22.

**[0032]** FIG. 24 is a perspective view of the antenna assembly of FIG. 1 positioned in an antenna cover of the nozzle cap assembly of FIG. 22.

**[0033]** FIG. 25 is a perspective view of a spacer of the nozzle cap assembly of FIG. 22 positioned within the antenna cover of FIG. 24.

**[0034]** FIG. 26 is a perspective view of another aspect of the nozzle cap assembly of FIG. 22 with a coupling.

**[0035]** FIG. 27 is a perspective view of the coupling of FIG. 26.

**[0036]** FIG. 28 is a perspective view of an antenna structure of the coupling of FIG. 26.

**[0037]** FIG. 29 is another perspective view of the antenna structure of the coupling of FIG. 26.

**[0038]** FIG. 30 is a perspective view of a radio canister with a coupling configured to communicate with the coupling of FIG. 26.

**[0039]** FIG. 31 is an exploded view of an antenna assembly according to another aspect of the present disclosure.

**[0040]** FIG. 32 is a partially-exploded view of a printed circuit board (PCB) assembly and an antenna cover having a cover radio frequency (RF) connector of the antenna assembly of FIG. 31.

**[0041]** FIG. 33 is a perspective view of the cover RF connector of FIG. 32.

**[0042]** FIG. 34 is a perspective view of the cover RF connector and PCB assembly of FIG. 32.

**[0043]** FIG. 35 is a perspective view of the PCB assembly of FIG. 32 disassembled.

**[0044]** FIG. 36 is a perspective view of a hydrant with a nozzle cap assembly including an antenna assembly according to another aspect of the present disclosure.

**[0045]** FIG. 37 is a perspective view of the hydrant with the nozzle cap assembly of FIG. 36 with an additional view of the nozzle cap assembly of FIG. 36 with a nozzle cap cover removed to show an interior of the nozzle cap assembly.

**[0046]** FIGs. 38A and 38B show two perspective views of the nozzle cap assembly of FIG. 36 in another aspect.

**[0047]** FIG. 39 is a perspective view showing a depth comparison between the nozzle cap assembly of FIG. 36 and a standard nozzle cap.

**[0048]** FIG. 40 shows perspective views of various aspects of the nozzle cap assembly of FIG. 36.

**[0049]** FIG. 41 shows a perspective view of the nozzle cap assembly of FIG. 36.

**[0050]** FIG. 42 shows an exploded perspective view of the nozzle cap assembly of FIG. 36.

**[0051]** FIG. 43 shows another exploded perspective view of the nozzle cap assembly of FIG. 36 with the antenna assembly of the nozzle cap assembly nested in an antenna cover of the nozzle cap assembly.

**[0052]** FIG. 44 is another exploded perspective view of the nozzle cap assembly of FIG. 36 with the antenna assembly nested in the antenna cover.



**[0053]** FIG. 45 is a perspective view of the nozzle cap assembly of FIG. 36 with the nozzle cap cover removed.

**[0054]** FIG. 46 is a perspective view of the nozzle cap assembly of FIG. 36 with the nozzle cap cover removed and with the antenna cover shown transparent to show the antenna assembly between the antenna cover and a nozzle cap housing.

**[0055]** FIG. 47 is a perspective view of one aspect of a nozzle cap assembly with a nozzle cap cover removed showing an interior cavity of a nozzle cap housing with an inner cover installed over a PCB.

**[0056]** FIG. 48 is a perspective view of the nozzle cap assembly of FIG. 47 with the nozzle cap cover, an antenna cover, and an antenna assembly removed showing a Reed sensor positioned within a port.

**[0057]** FIG. 49 is a top view of an aspect of the nozzle cap assembly of FIG. 47 with the nozzle cap cover, the antenna cover, the antenna assembly, and the inner cover removed showing the PCB.

**[0058]** FIG. 50 is a perspective view of the nozzle cap assembly of FIG. 47 with the nozzle cap cover, the antenna cover, the antenna assembly, the inner cover, capacitors, and batteries removed showing the PCB supported on PCB standoffs and an acoustic sensor mounted to the nozzle cap housing.

#### **DETAILED DESCRIPTION**

**[0059]** The present invention can be understood more readily by reference to the following detailed description, examples, drawings, and claims, and their previous and following description. However, before the present devices, systems, and/or methods are disclosed and described, it is to be understood that this invention is not limited to the specific devices, systems, and/or methods disclosed unless otherwise specified, and, as such, can, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular aspects only and is not intended to be limiting.

**[0060]** The following description of the invention is provided as an enabling teaching of the invention in its best, currently known aspect. To this end, those skilled in the relevant art will recognize and appreciate that many changes can be made to the various aspects of the invention described herein, while still obtaining the beneficial results of the present invention. It will also be apparent that some of the desired benefits of the present invention can be obtained by selecting some of the features of the present invention without utilizing other features. Accordingly, those who work in the art will recognize that many modifications and adaptations to

the present invention are possible and can even be desirable in certain circumstances and are a part of the present invention. Thus, the following description is provided as illustrative of the principles of the present invention and not in limitation thereof.

**[0061]** As used throughout, the singular forms “a,” “an” and “the” include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to “a band” can include two or more such bands unless the context indicates otherwise.

**[0062]** Ranges can be expressed herein as from “about” one particular value, and/or to “about” another particular value. When such a range is expressed, another aspect includes from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent “about,” it will be understood that the particular value forms another aspect. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint.

**[0063]** As used herein, the terms “optional” or “optionally” mean that the subsequently described event or circumstance can or cannot occur, and that the description includes instances where said event or circumstance occurs and instances where it does not.

**[0064]** The word “or” as used herein means any one member of a particular list and also includes any combination of members of that list. Further, one should note that conditional language, such as, among others, “can,” “could,” “might,” or “can,” unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain aspects include, while other aspects do not include, certain features, elements and/or steps. Thus, such conditional language is not generally intended to imply that features, elements and/or steps are in any way required for one or more particular aspects or that one or more particular aspects necessarily include logic for deciding, with or without user input or prompting, whether these features, elements and/or steps are included or are to be performed in any particular aspect. Directional references such as “up,” “down,” “top,” “left,” “right,” “front,” “back,” and “corners,” among others are intended to refer to the orientation as illustrated and described in the figure (or figures) to which the components and directions are referencing.

**[0065]** In one aspect, disclosed is an antenna assembly and associated methods, systems, devices, and various apparatus. The antenna assembly can comprise a curved printed circuit board (PCB) and a plurality of antenna structures configured to provide directional radiation in at least one frequency band. It would be understood by one of skill in the art that the disclosed antenna assembly is described in but a few exemplary aspects among many.

**[0066]** As shown in Figure 1, an antenna assembly 100 can comprise a PCB 102 and a plurality of antenna structures 104. In one aspect, it is contemplated that the PCB 102 can be a flexible PCB. For example and without limitation, it is contemplated that the material used to construct the PCB 102 can be selected from the group including, but not limited to, polyimide, polyethylene terephthalate (PET), and various other conventional materials used to construct flexible PCBs. In this aspect, Figure 1 shows the PCB 102 in an unwrapped configuration. In one aspect, it is contemplated that the curved PCB 102 can be bent into a wrapped configuration, for example as shown in Figure 13, and can be mounted or positioned around a curved surface, such as a fire hydrant, light poles, various utility structures having curved surfaces, decorative columns, curved structural supports, and various other types of structures having curved surfaces.

**[0067]** The PCB 102 can comprise a body 120, which can comprise a top end 106, a bottom end 108 distal from the top end 106, a first side end 110 adjacent to the top end 106 and the bottom end 108, and a second side end 112 distal from the first side end 110 and adjacent to the top end 106 and the bottom end 108. Optionally, the top end 106 and the bottom end 108 can define curved edges extending from the first side end 110 to the second side end 112. The type of edges formed by the top end 106 and the bottom end 108 should not be considered limiting on the current disclosure as it is also contemplated that the top end 106 and the bottom end 108 can define straight edges, jagged edges, and various other shapes of edges. In one aspect, the PCB 102 can comprise an outward-facing side 114 and an inward-facing side 502 (shown in Figure 5).

**[0068]** As shown in Figure 1, the antenna assembly 100 can comprise solder pads 116A–E which can be configured to be soldered to various cables (not shown), respectively, such as coaxial cables, which may be connected to various connectors or transceivers (not shown). In various other aspects, various other types of connectors can be utilized in place of the solder pads 116. It will be appreciated that the number or location of the solder pads 116 should not be considered limiting on the current disclosure as it is also contemplated that the number or location of the solder pads 116 may be varied depending on a particular use, purpose, or configuration of the antenna assembly 100. The PCB 102 can also define a number of through holes 118A–G, which may be utilized to mount various components onto the PCB 102 or secure the curved PCB 102 to various other items or devices. The number of through holes 118 should not be considered limiting on the current disclosure.

**[0069]** As shown in Figure 1, in various aspects, the antenna assembly 100 can comprise two or more antenna structures 104. Optionally, the multiple antenna structures 104 are contained

on a single medium, such as the PCB 102. In various aspects, the multiple antenna structures 104 can be designed or configured to operate in different frequency ranges to allow multiple types of services. An antenna assembly 100 having multiple antenna structures 104 operating in multiple frequency bands can be referred to as a “multi-band antenna assembly.” Optionally, multi-band antenna assemblies can also be formed on a single PCB to allow communication in multiple frequency ranges.

**[0070]** In one aspect, the antenna structures 104 can be configured to provide directional radiation in at least one frequency band. Optionally, as shown in Figure 1, the antenna structures 104 can be disposed on the outward-facing side 114 of the PCB 102. One skilled in the art will appreciate that the antenna structures 104 can be disposed on at least one of the outward-facing side 114 and the inward-facing side 502 of the PCB 102.

**[0071]** In the various aspects, the antenna assembly 100 can comprise: a plurality of first antenna structures 104A configured to operate within a first set of frequency bands; a plurality of second antenna structures 104B configured to operate within a second set of frequency bands; and a plurality of third antenna structures 104C configured to operate within a third set of frequency bands. It is contemplated that the antenna structures 104A–C can have various designs and configurations for operating within various frequency bands. Optionally, various other antenna structures configured to operate in additional or different sets of frequency bands can be utilized.

**[0072]** It will be appreciated that the number of each of the antenna structures 104A–C, respectively, should not be considered limiting on the current disclosure as it is contemplated that various combinations of antenna structures 104 may be utilized. For example and without limitation, in various aspects, the plurality of antenna structures 104 can be all first antenna structures 104A, all second antenna structures 104B, all third antenna structures 104C, all other types of antenna structures not currently shown, a combination of first antenna structures 104A and second antenna structures 104B, a combination of first antenna structures 104A and third antenna structures 104C, a combination of second antenna structures 104B and third antenna structures 104C, a combination of first antenna structures 104A and additional antenna structures configured to operate within different or additional frequency bands, etc.

**[0073]** In a further aspect, the antenna structures 104 can be configured to provide 360° directional radiation around a perimeter of a curved surface when the PCB 102 is mounted on the curved surface. Optionally, each one of the antenna structures 104 can be disposed on the PCB 102 such that each antenna structure provides a degreed section of radio coverage. In this aspect, the number and or type of antenna structures 104 disposed on the PCB 102 can be

varied to provide different sections of radio coverage. For example and without limitation, in various aspects, the eight antenna structures 104 can be disposed and spaced on the PCB 102 where each one of the plurality of antenna structures 104 provides a 45° section of radio coverage. As another example, three antenna structures 104 can be disposed and spaced on the PCB 102 where each of the antenna structures 104 provides a 120° section of radio coverage. It is contemplated that various other sections of radio coverage can be provided by changing at least one of the number of antenna structures 104, the spacing of antenna structures 104 on the PCB 102, and the type of antenna structures 104 utilized.

**[0074]** In one aspect, all of the antenna structures 104 in sum can provide 360° radio coverage while each set of frequency bands covered by the antenna structures 104 may not have 360° coverage. For example and without limitation, an antenna assembly 100 comprising one first antenna structure 104A, one second antenna structure 104B, and one third antenna structure 104C, each antenna structure 104A–C can provide a 120° section of radio coverage in each of the corresponding set of frequency bands, respectively, to, in sum, provide 360° radio coverage while each set of frequency bands only has a 120° section of radio coverage.

**[0075]** In another aspect, each set of frequency bands covered by the antenna structures 104 may have 360° coverage around the curved surface. For example and without limitation, in an antenna assembly 100 comprising three first antenna structures 104A, three second antenna structures 104B, and three third antenna structures 104C, each antenna structure 104A–C can provide 360° radio coverage in 120° sections of radio coverage in each of the corresponding set of frequency bands, respectively. Referring to Figure 1, in one non-limiting example, three first antenna structures 104A can be disposed on the PCB 102 to provide 360° coverage in 120° sections of radio coverage in at least one frequency band of the first set of frequency bands around the curved surface when the PCB 102 is bent. Additionally, three second antenna structures 104B can be disposed on the PCB 102 to provide 360° coverage in 120° sections of radio coverage in at least one of the second set of frequency bands around the curved surface when the PCB 102 is bent. Further, three third antenna structures 104C can be disposed on the PCB 102 to provide 360° coverage in 120° sections of radio coverage for at least one of the third set of frequency bands around the curved surface when the PCB 102 is bent.

**[0076]** In one preferred aspect, the antenna structures 104 can be configured to provide directional radiation in various sets of frequency bands currently developed or that may be developed in the future. For example and without limitation, the sets of frequency bands can be ranging from about 600 MHz to about 6 GHz; however, it is contemplated that the antenna structures 104 can be configured to operate at various other frequency bands below about 600

MHz or above about 6 GHz. In further aspects, the antenna structures 104 can be configured to provide radio coverage for Cellular, Cellular LTE, ISM 900, ISM 2400, GPS, and various other bands already developed or that may be developed in the future. For example and without limitation, the antenna structures can be configured to operate in various cellular bands such as 700, 800, 900, 1700, 1800, 1900, and 2100 MHz, as well as additional cellular bands currently developed or that can be developed in the future (e.g. cellular bands between 2 GHz and 6 GHz). As another example, the antenna structures 104 can be configured to operate in GPS bands, such as 1575.42 (L1) and 1227.60 MHz (L2), or in a wideband frequency range for wireless local area communication (e.g. Wi-Fi communication), such as a range from about 1.5 GHz to about 5.0 GHz, such as from about 2.0 GHz to about 5.0 GHz, any of which are currently developed bands or bands that may be developed in the future.

**[0077]** Referring to Figure 1, the first antenna structures 104A can be cellular antenna structures configured to provide radio coverage for Cellular/ISM bands ranging from about 600 MHz to about 6 GHz, the second antenna structures 104B can be cellular antenna structures configured to provide radio coverage for Cellular/LTE bands ranging from about 600 MHz to about 6 GHz, and the third antenna structures 104C can be wireless local area antenna structures configured to provide radio coverage for GPS bands ranging from about 1.5 GHz to about 5.0 GHz. However, it is contemplated that the antenna structures 104A–C can provide radio coverage for various other sets of frequency bands.

**[0078]** Referring to Figures 2–4, the PCB 102 can comprise a base layer 202, a copper layer 302, and a cover layer 402. In various aspects, the antenna structures 104 can be components of the copper layer 302, which can be disposed between the base layer 202 and the cover layer 402 of the assembled PCB 102. In various aspects, an adhesive (not shown) can be utilized between the copper layer 302 and the base layer 202 and between the copper layer 302 and the cover layer 402, respectively, to attach the copper layer 302 to the base layer 202 and the cover layer 402.

**[0079]** Referring to Figure 2, the base layer 202 can comprise a body 204 having an outward-facing side 208 and an inward-facing side 504 (shown in Figure 5). In various aspects, the inward-facing side 504 can be the inward-facing side 502 of the PCB 102. In various aspects, the body 204 can define the through holes 118A–G extending through the body 204 from the outward-facing side 208 to the inward-facing side 504. The body 204 can also define solder pad holes 206A–E extending through the body 204 from the outward-facing side 208 to the inward-facing side 504. It is contemplated that the number of solder pad holes 206 defined by the body 204 can correspond with the number of solder pads 116 of the antenna assembly 100.

**[0080]** Referring to Figure 3, the copper layer 302 can comprise a body 304 having an outward-facing side 306 and an inward-facing side (not shown). In various aspects, as described previously, the copper layer 302 can define the antenna structures 104. The body 404 can also define the through hole 118D. In another aspect, the copper layer 302 can define notches 308A–F. In one aspect, the notch 308A can be aligned with the through hole 118A, the notch 308B can be aligned with the through hole 118B, the notch 308C can be aligned with the through hole 118C, the notch 308D can be aligned with the through hole 118E, the notch 308E can be aligned with the through hole 118F, and the notch 308F can be aligned with the through hole 118G. One having skill in the art will appreciate that the number of notches 308 defined by the copper layer 302 should not be considered limiting on the current disclosure. In various aspects, the inward-facing side of the copper layer 302 can be positioned on the outward-facing side 208 of the base layer 202 to assemble the PCB 102.

**[0081]** Referring to Figure 4, the cover layer 402 can comprise a body 404 having an outward facing side 404 and an inward-facing side (not shown). In various aspects, as shown in Figure 4, the cover layer 402 can define the through holes 118A–G. In various aspects, the inward-facing side of the cover layer 402 can be positioned on the outward-facing side 306 of the copper layer 302 to assemble the PCB 102. In various aspects, the outward facing side 406 of the cover layer 402 can be the outward-facing side 114 of the PCB 102.

**[0082]** Referring to Figure 5, portions of the solder pads 116 can extend through the PCB 102 to the inward-facing side 502.

**[0083]** Referring to Figure 6, another example of the antenna assembly 100 is shown. As shown in Figure 6, the antenna assembly 100 can comprise the antenna structures 104D–F, which can be configured to operate within different frequency bands, additional frequency bands, or the same frequency bands, respectively, as those of antenna structures 104A–C. In one aspect, the antenna assembly 100 can comprise a securing tab 606 connected to the body 120 via a bend line 608. In one aspect, the bend line 608 can be a designed weakened region at which the securing tab 606 can be bent relative to the body 120. The securing tab 606 can comprise electrical connectors 610A,B in electrical communication with the antennas 104D–F such that the antennas 104D–F can be connected to various connectors or transceivers (not shown). In various aspects, the securing tab 606 can comprise mechanical connectors or fasteners 612A,B, which can be utilized to mechanically connect or secure the antenna assembly 100 to various structures or devices. It is contemplated that the mechanical connectors or fasteners 612A,B can be, for example and without limitation, nuts and bolts, screws, pins, and various other types of connectors which can be utilized to secure the antenna

assembly 100 to the various other structures or devices. It will be appreciated that the number of electrical connectors 610 or mechanical connectors 612 should not be considered limiting on the current disclosure as it is also contemplated that any desired number of electrical connectors 610 or mechanical connectors 612 can be utilized.

**[0084]** Referring to Figure 7, another example of an antenna assembly 700 is shown. Similar to the antenna assembly 100, the antenna assembly 700 can comprise a PCB 702 and antenna structures 104. Antenna structures 104G,H can be configured to operate within different frequency bands, additional frequency bands, or the same frequency bands, respectively, as those of antenna structures 104A–E. In another aspect, as shown in Figure 7, the antenna assembly 700 includes two antenna structures 104E.

**[0085]** The PCB 702 can comprise a body 704 having a top side 706 and a bottom side 708. As shown in Figure 7, the body 704 can optionally have a substantially circular shape that defines a substantially circular-shaped bore 710. One skilled in the art will appreciate that other geometric shapes of the body 704 or the bore 710 can be present. In a further aspect, the PCB 702 can comprise electrical connectors 710A,B, which can be substantially similar to the electrical connectors 610A,B of the antenna assembly 600. In one aspect, the electrical connectors 710A,B can be connected to the antenna structures 104.

**[0086]** Optionally, as shown in Figure 7, various additional structures or components can be positioned or secured to the antenna assembly 700. For example and without limitation, the additional structures or components positioned or secured to the antenna assembly 700 can be a modem 712, power supplies 714A,B such as batteries or various other power sources, sensors (not shown), or various other structures or components as desired.

**[0087]** Referring to Figures 8–13, an example of a nozzle cap assembly 800 utilizing the antenna assembly 100 is illustrated. The nozzle cap assembly 800 can comprise a nozzle cap 802, a spacer 1002 (shown in Figure 10), the antenna assembly 100, and an antenna cover 804. The nozzle cap 802 can be configured to mount on a nozzle of a node of an infrastructure system, such as on a fire hydrant (not shown). The nozzle cap 802 can comprise attachment mechanisms, such as threading, pins, fasteners, clips, and various other types of attachment mechanisms such that the nozzle cap 802 can be removable from the fire hydrant.

**[0088]** Referring to Figure 9, in one aspect, the nozzle cap 802 can comprise a body 902 having a top end 912 and a bottom end 914. As shown in Figure 9, the nozzle cap 802 can comprise a base 904 at the top end 912 and a curved side wall 906 extending from the base 904 to the bottom end 914. The base 904 can have an inner surface 1202 (shown in Figure 12) and an outer surface 908. The curved side wall 906 can have an inner surface 1204 (shown in



Figure 12) and an outer surface 910. The outer surface 910 can define spacer tabs 918A,B for attachment of the nozzle cap 802 to the spacer 1002. Two spacer tabs 918A,B are defined in Figure 9, but any number of spacer tabs 918 can be present in other aspects. Referring to Figure 12, the inner surface 1202 and the inner surface 1204 together can define a nozzle cap cavity 1206 having a nozzle cap cavity opening 1210 at the bottom end 914. The inner surface 1204 can define threading 1208, which can provide an attachment mechanism for the nozzle cap 802 that engages with threading on the fire hydrant such that the nozzle cap 802 may be removably attached to the fire hydrant. However, it is contemplated that various other types of attachment mechanisms other than the threading 1208 may be utilized.

**[0089]** The nozzle cap 802 can comprise a nut base 806 extending axially upwards from the outer surface 908 of the base 904. The nut base 806 can be utilized by an operator to aid in removing the nozzle cap 802 from the fire hydrant or securing the nozzle cap 802 to the fire hydrant. The base 904 of the nozzle cap 802 can define a plurality of cable holes 916 proximate to the nut base 806 that extend from the inner surface 1202 to the outer surface 908. Four cable holes 916 are shown in the base 904, though any number of cable holes 916 can be present in other aspects. The cable holes 916 are sized to accept one or more antenna coaxial cables connected to a radio canister (not shown) housed within the nozzle cap 802. The one or more coaxial cables extend through the cable holes 916 to connect with the antenna assembly 100 at any of the solder pads 116.

**[0090]** Referring to Figure 8, the antenna cover 804 can comprise a body 808 having a top end 822 and a bottom end 824. In various aspects, the antenna cover 804 can comprise a base 810 at the top end 822 and a curved side wall 812 extending from the base 810 to the bottom end 824. The base 810 can have an inner surface (not shown) and an outer surface 814. The curved side wall 812 can have an inner surface (not shown) and an outer surface 816. The inner surface of the base 810 and the inner surface of the curved side wall 812 together can define an antenna cover cavity (not shown), into which the nozzle cap 802, the spacer 1002, and antenna assembly 100 can optionally be positioned.

**[0091]** Optionally, as shown in Figure 8, in various aspects, the base 810 can define a cover bore 818 at the top end 822 extending through the antenna cover 804 from the inner surface to the outer surface 814. Optionally, the nut base 806 can extend through the cover bore 818 such that the nut base 806 may be accessed by the operator when the antenna cover 804 is positioned on the nozzle cap 802.

**[0092]** Referring to Figure 10, the spacer 1002 can comprise a hollow body 1004 having a top end 1006, a bottom end 1008, a curved inner surface 1010, and a curved outer surface 1012.

Optionally, the hollow body 1004 can be shaped like a truncated cone. One skilled in the art will appreciate that other geometric shapes, for example and without limitation a substantially cylindrical shape, can be present. In various aspects, the spacer 1002 can comprise a top lip 1014 at the top end 1006 and a bottom lip 1016 at the bottom end 1008. In this aspect, the top lip 1014 can extend radially inward from the top end 1006 towards a center axis 1018 of the spacer 1002. Similarly, the bottom lip 1016 can extend radially inward from the bottom end 1008 towards the center axis 1018 of the spacer 1002.

**[0093]** Figure 11 shows the spacer 1002 mounted on the nozzle cap 802. In one aspect, the spacer 1002 can be sized to approximate a width or diameter of the nozzle cap 802. In another aspect, the spacer 1002 can be mounted on the nozzle cap 802 such that the curved inner surface 1010 of the body 1004 of the spacer 1002 faces the outer surface 910 of the curved side wall 906 of the nozzle cap 802. In another aspect, a distance from the top lip 1014 to the bottom lip 1016 of the spacer 1002 can be greater than a distance from the top end 912 to the bottom end 914 of the nozzle cap 802. In this aspect, the top lip 1014 and the bottom lip 1016 can be utilized to retain the spacer 1002 on the nozzle cap 802 via a snap-fit configuration by positioning the nozzle cap 802 between the top lip 1014 and the bottom lip 1016, with the top lip 1014 engaging the spacer tabs 918A,B and the bottom lip 1016 engaging the bottom end 824 of the nozzle cap 802. The antenna cover 804 can be placed over the spacer 1002 mounted on the nozzle cap 802. In various aspects, the base 904 can define a raised portion 1102.

**[0094]** Figure 12 shows another view of the spacer 1002 mounted on the nozzle cap 802. Figure 12 also shows the threading 1208 and the nozzle cap cavity 1206 of the nozzle cap 802.

**[0095]** Referring to Figure 13, it is contemplated that the PCB 102 can be bent or formed into an annular shape to form a curved PCB. Optionally, the PCB 102 can be bent to form a hollow cylindrical shape, as shown for example and without limitation in Figure 13. One skilled in the art will appreciate that the PCB 102 can be bent to form other geometric shapes, such as, for example and without limitation, a truncated cone shape as shown in Figure 13.

**[0096]** In one aspect, the PCB 102 of the antenna assembly 100 can be formed into a curved shape and mounted around the curved side wall 906 of the nozzle cap 802 of the fire hydrant. As previously described, it is contemplated that the PCB 102 can be configured to be mounted around various other curved surfaces such as around light poles, various utility structures having curved surfaces, decorative columns, curved structural supports, and various other types of structures. In the aspect where the antenna assembly 100 is mounted on the nozzle cap 802, the antenna assembly 100 can maintain at least one section of the antenna assembly 100 facing upwards, regardless of the rotation end stop of the nozzle cap 802 when mounted on the

hydrant. In one aspect, it is contemplated that fasteners (not shown) can be utilized with the through holes 118 to secure the PCB 102 to the antenna assembly 100. However, it is also contemplated that the PCB 102 can be secured to the antenna assembly 100 through various other fastening mechanisms that may or may not utilize the through holes 118.

**[0097]** In one aspect, the antenna assembly 100 can be mounted such that the spacer 1002 can be between the nozzle cap 802 and the antenna assembly 100. In this aspect, the inward-facing side 502 of the antenna assembly 100 can face the curved outer surface 1012 of the spacer 1002. In another aspect with the antenna cover 804, the outward-facing side 114 can face the inner surface of the curved side wall 812 of the antenna cover 804.

**[0098]** Referring to Figures 14–20, an example of a nozzle cap assembly 1400 utilizing the antenna assembly 100 of Figure 6 is illustrated. The nozzle cap assembly 1400 can comprise a nozzle cap 1402, a mounting plate 1404, an antenna cover 1406, and the antenna assembly 100.

**[0099]** In one aspect, the nozzle cap 1402 can comprise a body 1408 having a top end 1410 and a bottom end 1412. The nozzle cap 1402 can comprise a base 1422 at the top end 1410 and a curved side wall 1414 extending from the base 1422 to the bottom end 1412. The base 1422 can comprise an inner surface (not shown) and an outer surface 1424 and the curved side wall 1414 can comprise an inner surface (not shown) and an outer surface 1416. The inner surfaces of the base 1422 and curved side wall 1414, respectively, can together define a nozzle cap cavity, which can be similar to the nozzle cap cavity 1206.

**[0100]** Optionally, the nozzle cap 1402 can define an alignment groove 1418 in the body 1408 at the top end 1410. In one aspect, the alignment groove 1418 can extend around a perimeter of the base 1422. As described in greater detail below, in one aspect, the alignment groove 1418 can be utilized by the operator to position and lock the antenna cover 1406 on the nozzle cap 1402.

**[0101]** In another aspect, the nozzle cap 1402 can comprise a nut base 1420 extending axially upwards from the base 1422. Compared to the nut base 806, the nut base 1420 can be elongated to accommodate the antenna cover 1406, mounting plate 1404, and antenna assembly 100 at a position axially above the base 1422. However, it is contemplated that the nut base 1420 can also be a conventionally-sized nut base that may not be elongated.

**[0102]** Optionally, the nozzle cap 1402 can comprise various devices or structures mounted at various locations on the body 1408. For example and without limitation, in one aspect, the nozzle cap 1402 can comprise a sensor 1426, such as a leak sensor, vibration sensor, tamper sensor, or various other types of sensors, secured on the base 1422.

**[0103]** In one aspect, as shown in Figures 14 and 16, the mounting plate 1404 can comprise a body 1428 with a top surface 1430 and a bottom surface 1602. Optionally, the body 1428 can be an annular shape defining a substantially circular shaped bore 1432. One having skill in the art will appreciate that other geometric shapes of the body 1428 and the bore 1432 can be present. In one aspect, the bore 1432 can be dimensioned such that the mounting plate 1404 can be positioned on the nozzle cap 1402 with the nut base 1420 extending through the bore 1432.

**[0104]** Optionally, the mounting plate 1404 can define various other bores to accommodate any devices or structures mounted on the base 1422 of the nozzle cap 1402. For example and without limitation, in the aspect where the nozzle cap 1402 can comprise the sensor 1426, the mounting plate 1404 can define a sensor bore 1434 through which the sensor 1426 can extend.

**[0105]** Optionally, in a further aspect, the mounting plate 1404 can comprise various additional structures or components positioned or secured to the mounting plate 1404. For example and without limitation, the additional structures or components positioned or secured to the mounting plate 1404 can be the modem 712, the power supplies 714A,B, an additional PCB 1458, or various other structures or components as desired.

**[0106]** In one aspect, the antenna cover 1406 can be similar to the antenna cover 804 and can comprise a body 1436 having a top end 1438 and a bottom end 1440. In one aspect, the antenna cover 1406 can comprise a base 1442 at the top end 1438 and an outer wall 1444 extending from the base 1442 to the bottom end 1440. Referring to Figures 14, 16, and 17, the base 1442 can have an outer surface 1446 and an inner surface 1702 and the outer curved wall 1444 can have an outer surface 1448 and an inner surface 1604. The inner surface 1702 and the inner surface 1604 together can define an antenna cover cavity 1606. Optionally, the outer wall 1444 can be a cylindrical shape; however, it will be appreciated that other geometric shapes of the outer wall 1444 can be present.

**[0107]** In another aspect, an alignment lip 1454 can extend axially downwards from the outer wall 1444 at the bottom end 1440. In this aspect, the alignment lip 1454 can be dimensioned and shaped such that the alignment lip 1454 can be positioned within the alignment groove 1418. In a further aspect, the alignment lip 1454 within the alignment groove 1418 can position and secure the antenna cover 804 on the nozzle cap 1402.

**[0108]** Optionally, as shown in Figure 14, the base 1442 can define a cover bore 1450 in one aspect. In another aspect, the antenna cover 1406 can comprise an inner wall 1452 surrounding the cover bore 1450 and extending axially downwards from the inner surface 1702 of the base 1442 into the antenna cover cavity 1606 to a bottom end 1608, as shown in Figure 16. The

inner wall 1452 can comprise an inner surface 1456 and an outer surface 1704, as shown in Figure 17. Optionally, the cover bore 1450 can be a substantially circular-shaped bore and the inner wall 1452 can be a cylindrical shape; however, one skilled in the art will appreciate that other geometric shapes of the cover bore 1450 and inner wall 1452 can be present.

**[0109]** Referring to Figure 18, in one aspect, the securing tab 606 of the antenna assembly 100 can be bent along the bend line 608 and the mechanical connectors or fasteners 612A,B can be utilized to secure the antenna assembly 100 to the mounting plate 1404. Optionally, the antenna assembly 100 can be secured to the mounting plate 1404 such that the antenna assembly 100, other than the securing tab 606, can be substantially perpendicular to the mounting plate 1404.

**[0110]** Referring to Figure 19, the mounting plate 1404 can be positioned on the nozzle cap 1402 such that the nut base 1420 extends through the bore 1432. In one aspect, the bottom surface 1602 can face and can be in contact with the outer surface 1424 of the base 1422 of the nozzle cap 1402.

**[0111]** Referring to Figure 20, the antenna cover 1406 can be positioned on the nozzle cap 1402 such that the nut base 1420 extends through the cover bore 1450. Optionally, as described previously, the alignment lip 1454 can be positioned in the alignment groove 1418. In one aspect, the antenna assembly 100 and mounting plate 1404 can be housing within the antenna cover cavity 1606 when the antenna cover 1406 is positioned on the nozzle cap 1402.

**[0112]** Referring to Figure 21, in another aspect, the antenna assembly 700 can be used with the antenna cover 1406. In this aspect, the antenna assembly 700 can be positioned in the antenna cover cavity 1606. In a further aspect, the bottom side 708 of the PCB 702 can be facing and can be in contact with the inner surface 1702 of the base 1442 of the antenna cover 1406, and can be attached to the inner surface 1702 by screws, pressure-fitted tabs, melted tabs or stubs, adhesives, or any similar fastening devices. In another aspect, the inner wall 1452 of the antenna cover 1406 can extend through the bore 710 of the antenna assembly 700. In one aspect, the antenna assembly 700 and antenna cover 1406 can be mounted on the nozzle cap 1402 in a similar manner as described above to form a nozzle cap assembly that looks like the nozzle cap assembly 1400 shown in Figure 20.

**[0113]** Referring to Figures 22–25, an example of a nozzle cap assembly 2200 utilizing the antenna assembly 100 of Figure 6 is illustrated. In one aspect, the nozzle cap assembly 2200 can comprise a nozzle cap 2202, an antenna cover 2204, and a spacer 2502.

**[0114]** Referring to Figures 22, 23, and 26 in one aspect, the nozzle cap 2202 can comprise a body 2302 having a top end 2304 and a bottom end 2306. The nozzle cap 2202 can comprise a base 2308 at the top end 2304 and a curved side wall 2310 extending from the base 2308 to the

bottom end 2306. The base 2308 can comprise an inner surface 2602 and an outer surface 2312 and the curved side wall 2310 can comprise an inner surface 2604 and an outer surface 2314. The inner surfaces of the base 2308 and curved side wall 2310, respectively, can together define a nozzle cap cavity 2606.

**[0115]** In another aspect, the nozzle cap 2202 can comprise a nut base 2206 extending axially upwards from the base 2308. In yet another aspect, the nozzle cap 2202 optionally can define a through hole 2316 in the base 2308. In one aspect, the through hole 2316 can be utilized to guide a cable through the nozzle cap 2202.

**[0116]** Referring to Figures 22 and 24, the antenna cover 2204 can comprise a body 2208 having a top end 2210 and a bottom end 2212. In various aspects, the antenna cover 2204 can comprise a base 2214 at the top end 2210 and a curved side wall 2216 extending from the base 2214 to the bottom end 2212. The base 2214 can have an inner surface 2402 and an outer surface 2218. The curved side wall 2216 can have an inner surface 2404 and an outer surface 2220. The inner surface of the base 2214 and the inner surface of the curved side wall 2216 together can define an antenna cover cavity 2406, into which the nozzle cap 2202, the spacer 2502, and the antenna assembly 100 can optionally be positioned.

**[0117]** Optionally, as shown in Figure 22, in various aspects, the base 2214 can define a cover bore 2222 at the top end 2210 extending from the inner surface 2404 to the outer surface 2218. Optionally, the nut base 2206 can extend through the cover bore 2222 such that the nut base 2206 may be accessed by the operator when the antenna cover 2204 is positioned on the nozzle cap 2202.

**[0118]** In yet another aspect, the antenna cover 2204 can optionally define a cable guide 2224. In one aspect, a portion of the cable guide 2224 can extend upwards from the base 2214 as shown in Figure 22. In another feature, the cable guide 2224 can define a guide opening 2408 that can be matched and aligned with the through hole 2316 to guide the cable through the antenna cover 2204. The cable guide 2224 allows the nozzle cap 2202 to be positioned closer to the antenna cover 2204 and protects the cable from damage or pinching between the nozzle cap 2202 and the antenna cover 2204. It is contemplated that the cable can connect to an external antenna (not shown) or various other structures or devices external to the nozzle cap assembly 2200 at one end and to a radio canister (not shown) or other structures at another end.

**[0119]** Referring to Figure 24, the antenna assembly 100 can be positioned and secured within the antenna cover 2204 such that the outward-facing side 114 faces the inner surface 2404 of the curved side wall 2216. In one aspect, the antenna cover 2204 can optionally define a

plurality of locking tabs 2410 extending inwards from the bottom end 2212. Optionally, the locking tabs 2410 can be substantially perpendicular to the curved side wall 2216; however, it is also contemplated that the locking tabs 2410 can have various other configurations relative to the curved side wall 2216. It will be appreciated the number or the shape of the locking tabs 2410 should not be considered limiting on the current disclosure as it is contemplated that any number of locking tabs 2410 having any desired shape may be utilized. For example and without limitation, in another aspect, the antenna cover 2204 can define a single, continuous locking tab 2410 extending inward from the bottom end 2212.

**[0120]** In a further aspect, the antenna cover 2204 can optionally define an inner wall 2412 extending downwards from the base 2214 into the antenna cover cavity 2406. In one aspect, a spacer alignment groove 2414 can be defined between the inner wall 2412 and the inner surface 2404 of the curved side wall 2216.

**[0121]** Referring to Figure 25, the spacer 2502 can comprise a hollow body 2504 having a top end 2506, a bottom end 2508, a curved inner surface 2510, and a curved outer surface (not shown). Optionally, the hollow body 2504 can be a substantially cylindrical shape; however, one skilled in the art will appreciate that other geometric shapes can be present. In one aspect, the locking tabs 2410 and the spacer alignment groove 2414 can be utilized by the operator to position and secure the spacer 2502 within the antenna cover 2204, as shown in Figure 25.

**[0122]** Referring to Figures 26–30, in another aspect, in place of the cable that can be guided through the through hole 2316 and cable guide 2224, the nozzle cap assembly 2200 can comprise a coupling 2608 mounted on the nozzle cap 2202. In one aspect, a portion of the coupling 2608 can be positioned within the through hole 2316. The coupling 2608 can be connected to the external antenna and can be wirelessly coupled to a radio canister 3002, which is shown in Figure 30.

**[0123]** Referring to Figures 26 and 27, the coupling 2608 can comprise a body 2702 having a top side 2710 and a bottom side 2712. The body 2702 can define an antenna assembly indentation 2704 into which an antenna assembly 2714 can be positioned. The body 2702 can also comprise a securing stem 2706. Optionally, the stem 2706 can be a substantially cylindrical shape defining a circular bore 2708; however, the shape of the stem 2706 or the bore 2708 should not be considered limiting on the current disclosure as it is contemplated that other geometric shapes of the stem 2706 and the bore 2708 can be present. In another aspect, the stem 2706 does not define the bore 2708. The stem 2706 can extend upwards from the top side 2710. In one aspect, the stem 2706 can be configured to be positioned within the through hole

2316. The shape of the body 2702 should not be considered limiting on the current disclosure as it is contemplated that various geometric shapes of the body 2702 can be present.

**[0124]** The antenna assembly 2714 can comprise a PCB 2716 and an antenna structure 2902 (shown in Figure 29). The PCB 2716 can comprise a top side 2718 and a bottom side 2802 (shown in Figure 28). In one aspect, the PCB 2716 can comprise the electrical connectors 610A,B. One skilled in the art will appreciate that the electrical connectors 610A,B can be disposed on at least one of the top side 2718 and the bottom side 2802 of the PCB 2716. The shape of the PCB 2716 should not be considered limiting on the current disclosure as it is contemplated that various other geometric shapes of the PCB 2716 can be present. In one aspect, it is contemplated that the PCB 2716 can be shaped such that the PCB 2716 can be positioned within the antenna assembly indentation 2704. In one aspect, the antenna assembly 2714 can be a multi-frequency PCB trace coil pad. Optionally, as shown in Figure 29, the antenna structure 2902 can be disposed on the bottom side 2802 of the PCB 2716. One skilled in the art will appreciate that the antenna structure 2902 can be disposed on at least one of the top side 2718 and the bottom side 2802 of the PCB 2716. In one aspect, the PCB 2716 can be configured for wireless communication with the radio canister 3002, such as through the use of inductive coupling, to eliminate the use of cables and allow for easier service and maintenance on the nozzle cap assembly 2200. Referring to Figure 30, the radio canister 2002 can comprise an antenna assembly 3004 that can be communicatively coupled to the antenna assembly 2714. In one aspect, the antenna assembly 2714 can be a multi-frequency PCB trace coil pad. In another aspect, it is contemplated that the antenna structures of the antenna assemblies 2714,3004 can be similar to the antenna structures 104 or different from the antenna structures 104, depending on application.

**[0125]** Referring to Figures 31–35, an example of an antenna assembly 3100 is illustrated. The antenna assembly 3100 can comprise a radio canister 3102 having a canister radio frequency (RF) connector 3108, a PCB assembly 3202 (shown in Figure 32), and an antenna cover 3104 having a cover RF connector 3106. The antenna cover 3104 can comprise a first end 3112, a second end 3114, an outer surface 3110, and an inner surface 3204. The inner surface 3204 can define an antenna cover cavity 3206. In one aspect, the antenna cover 3104 can comprise an antenna cover opening 3222 providing access to the cover cavity 3206 at the first end 3112. In one aspect, the antenna cover 3104 can be configured to receive the PCB assembly 3202 within the antenna cover cavity 3206.

**[0126]** In one aspect, the cover RF connector 3106 can define a body 3210. The body can comprise a canister-connecting portion 3212 and a PCB-connecting portion 3214. In one



aspect, the canister-connecting portion 3212 can comprise connectors 3208A,B configured to engage with connectors 3116A,B of the canister RF connector 3108. The number of connectors 3208 or connectors 3116 should not be considered limiting on the current disclosure as it is contemplated that any number of connectors 3208 or connectors 3116 can be present. In another aspect, the PCB-connecting portion 3214 can define slots 3216A,B configured to engage and receive the PCB assembly 3202. In one aspect, the PCB assembly 3202 can comprise two PCBs 3218A,B coupled together, as described in greater detail below. It is contemplated that the number of slots 3216 can correspond with the number of PCBs 3218 in various aspects. In another aspect, the cover RF connector 3106 can be positioned such that the PCB-connecting portion 3214 can be within the antenna cover cavity 3206 and an engagement edge 3220 of the canister-connecting portion 3212 engages the first end 3112 of the antenna cover 3104.

**[0127]** Referring to Figures 34 and 35, each PCB 3218A,B, respectively, can comprise at least one antenna structure 3404A,B, respectively. It is contemplated that in one aspect, that the antenna assembly 3100 can be configured for cellular quad-band and GPS coverage. In another aspect, it is contemplated that the antenna structures 3404 can be similar to the antenna structures 104 or different from the antenna structures 104, depending on application. The number or type of antenna structure 3404 on the PCBs 3218 should not be considered limiting as it is contemplated that various numbers, types, or combinations thereof of antenna structures 3404 can be present on each PCB 3218A,B, respectively. Additionally, the number of PCBs 3218 should not be considered limiting.

**[0128]** As shown in Figures 34 and 35, each PCB 3218A,B can define a first side end 3412A,B and a second side end 3414A,B distal from the first side end 3412A,B, respectively. In another aspect, each PCB 3218A,B can define a top side 3408A,B and a bottom side 3410A,B, respectively. In one aspect, each PCB 3218A,B defines an engagement slot 3406A,B, respectively, that can be utilized to couple the PCBs 3218A,B together. In another aspect, the engagement slots 3406A,B can extend from the second side ends 3414A,B partially through the PCBs 3218A,B towards the first side ends 3412A,B, respectively. In this aspect, each engagement slot 3406A,B can define a slot surface 3502A,B, respectively. The shape of the engagement slots 3406 should not be considered limiting on the current disclosure as it is contemplated that various shaped slots can be defined. In one aspect, the slots 3406A,B can be dimensioned to accept the PCBs 3218A,B within the slots 3406A,B, respectively. In this aspect, when the PCBs 3218A,B are assembled to form the PCB assembly 3202, the slot surface 3502A can cover a portion of the top side 3408B and a portion of the bottom side 3410B of the

PCB 3218B. Similarly, the slot surface 3502B can cover a portion of the top side 3408A and a portion of the bottom side 3410A of the PCB 3218A.

**[0129]** In one aspect, the PCBs 3218A,B can be combined such that the PCB assembly 3202 can have a general “x” shape. The PCB assembly 3202 can be positioned within the slots 3216A,B of the PCB-connecting portion 3214 of the cover RF connector 3106. In one aspect, the cover RF connector 3106 can be positioned such that the PCB-connecting portion 3214 and the PCB assembly 3202 is within the antenna cover cavity 3206. In one aspect, the shape of the PCBs 3218A,B can allow the PCB assembly 3202 to fit in the antenna cover opening 3222 and into the antenna cover cavity 3206. In another aspect, the PCBs 3218A,B combined via positioning in the slots 3405A,B can allow the antenna structures 3404 to face multiple directions without being bent or wrapped.

**[0130]** Figures 36–46 show another aspect of a nozzle cap assembly 4100 mounted on an outlet of the hydrant 3600. The nozzle cap assembly 4100 can be a pre-assembled and factory-tested node and, in various aspects, can comprise any of a cast iron hydrant cap, an acoustic sensor, a data processor, network hardware, batteries, or an antenna. In some aspects, the nozzle cap assembly 4100 can be configured as a sensing node which may comprise a sensor configured to monitor parameters of a fluid system such as pressure, temperature, pH, chemical concentration, acoustic vibrations, or other fluid characteristics. In one aspect, as shown in Figure 36, the nozzle cap assembly 4100 can be a wireless sensing node, such as an acoustic node comprising an antenna, acoustic sensor, processor and battery. The wireless acoustic node can be mounted on the hydrant 3600 and identify any leaks in a water main or distribution main (not shown) connected to the hydrant 3600. The acoustic node is capable of wireless transmission. Installation of the sensing nodes onto the hydrants of a fluid distribution network can create a smart fluid system. For example, in some aspects, an acoustic node can be mounted onto the hydrants of a water distribution main to create a smart water system or a smart water network when the acoustic node communicates with other devices wirelessly. The nozzle cap assembly 4100 can be designed to replace 4-inch or 4.5-inch pumper nozzle caps, or any other size pumper nozzle caps or other nozzle caps on a hydrant 3600 or on any other structure having a nozzle cap. The nozzle cap assembly is compatible with both wet- and dry-barrel fire hydrants. Figure 39 shows a depth comparison between the nozzle cap assembly 4100 and a standard version of a nozzle cap 3900. As shown in Figure 39, the nozzle cap assembly can be approximately 1.5 inches taller than the standard nozzle cap, i.e., there can exist a height difference 3910, though in other aspects the height difference 3910 can be larger or smaller than 1.5 inches. The nozzle cap assembly can be similar in appearance to the

standard nozzle cap which can be desirable in some applications. The nozzle cap assembly 4100 and any other nozzle cap assembly can also be customized to adapt the appearance to any hydrant color scheme as shown in Figure 40

**[0131]** As shown in Figures 41–46, the nozzle cap assembly 4100 can comprise a nozzle cap cover 4110, an antenna cover 4120, a nozzle cap housing 4130, and the antenna assembly 100. The nozzle cap cover 4110, the antenna cover 4120, and the nozzle cap housing 4130 can define a smooth outer side surface 4101. The nozzle cap cover 4110 can optionally define fastener holes 4111 therethrough. The fastener holes 4111 are sized to accept bolts 3801 (shown in Figure 38A). The bolts can have a standard Phillips-head, a slotted head, or any other type of head, including tamper-proof bolt heads. The nozzle cap cover 4110 can also comprise a nut base 4116. The nut base 4116 can have a hex, square (shown in Figure 38A), or any other desired shape configured to allow the nozzle cap assembly 4100 to be installed or removed on the hydrant outlet to allow use of the hydrant 3600. The nozzle cap housing 4130 can also comprise tabs 4131 for manipulation such as installation or removal of the nozzle cap assembly 4100 or for visual alignment of the nozzle cap assembly 4100 in a particular orientation on the hydrant 3600.

**[0132]** As shown in Figure 42, the antenna cover 4120 has a frustoconical shape, though other shapes, such as a cylindrical shape, can be present in various other aspects. The antenna cover 4120 is positioned and held securely in place between the nozzle cap cover 4110 and the nozzle cap housing 4130. The nozzle cap housing 4131 can comprise an antenna mounting portion 4132 and a lower rim 4133. The antenna mounting portion 4132 defines an antenna mounting surface 4134 having a frustoconical shape, though other shapes, including other curved shapes, such as a cylindrical shape, can be present in various other aspects. The antenna cover 4120 can fit around and cover the antenna mounting surface 4134 and can have a curved shape complimentary to the shape of the antenna mounting surface 4134. The lower rim 4133 can comprise a shoulder 4135 against which the antenna cover 4120 can be positioned to securely hold the antenna cover 4120 in place. In some aspects, the lower rim 4133 can define an antenna cover alignment tab 4830 (shown in Figure 48) which can engage a complimentary notch (not shown) in the antenna cover to prevent rotation of the antenna cover 4120. The antenna mounting portion 4132 can comprise fastener attachment tabs 4136 defining threaded fastener holes 4137 aligned with the fastener holes 4111 of the nozzle cap cover 4110. The nozzle cap cover 4110 can thereby be secured to the nozzle cap housing 4130 by the bolts 3801 extending through the fastener holes 4111 into the fastener holes 4137 and

engaging the threads therein, thereby securing the antenna cover 4120 and the antenna assembly 100 between the nozzle cap cover 4110 and the nozzle cap housing 4130.

**[0133]** The nozzle cap assembly 4100 can also comprise a flat sealing gasket 4210. The sealing gasket 4210 can extend around an upper rim 4138 and on an inner side of each fastener attachment tabs 4136 to seal between the nozzle cap cover 4110 and the nozzle cap housing 4130 and thereby prevent fluid such as rainwater from entering an interior cavity 4310 (shown in Figure 43) of the nozzle cap housing 4130.

**[0134]** The nozzle cap housing 4130 can define a plurality of PCB mounting holes 4220, which can be threaded. The PCB mounting holes are configured to receive a threaded male end of each of a plurality of standoffs 5021 (shown in Figure 50), which are used to mount and position the PCB.

**[0135]** As shown in Figures 43 and 44, the antenna assembly 100 fits within the antenna cover 4120 and is curved around an inner surface of the antenna cover 4120. The antenna assembly 100 can be adhered or otherwise fastened or secured to either or both of the inner surface of the antenna cover 4120 or the antenna mounting surface 4134. In other aspects, the antenna cover 4120 can define a top lip and a bottom lip similar to top lip 1014 and bottom lip 1016, respectively, to secure the antenna assembly 100 in place within the antenna cover 4120.

**[0136]** As shown in Figure 43, various electrical components operatively associated with the antenna assembly 100 can be housed within the nozzle cap housing 4130. These electrical components can comprise a PCB 4320, batteries 4330, and capacitors 4340. The nozzle cap housing 4130 can also house other components, including but not limited to an acoustic sensor or other sensor, antennas other than the antenna structure 104 on the antenna assembly 100, or other data processors or network hardware that can be operatively associated with the PCB 4320, the batteries 4330, the capacitors 4340, or the antenna assembly 100.

**[0137]** As shown in Figure 44, the nozzle cap housing 4130 can also define internal threading 4410 to allow the nozzle cap assembly 4100 on the outlet of the hydrant 3600. The nozzle cap housing 4130 can also comprise a divider wall 4420 to separate the internal threading 4410, and thereby the outlet of the fire hydrant 3600, from the electrical components housed within the nozzle cap housing 4130. The nozzle cap cover 4110 can also define tab receiving hole 4440 sized to receive the fastener attachment tabs 4136 therein. The tab receiving holes 4440 and the fastener attachment tabs 4136 thereby mate to prevent stress on the bolts 3801 during engagement of the nut base 4116 to rotate the nozzle cap assembly 4100.

**[0138]** As shown in Figures 45 and 46, the antenna assembly 100 is secured between the inner surface of the antenna cover 4120 and the antenna mounting surface 4134 in an antenna cover

cavity 4506. In various aspects, the nozzle cap cover 4110 and the nozzle cap housing 4130 can comprise cast or ductile iron or any other desired material for attachment to the fire hydrant 3600. The antenna cover can comprise polypropylene or other desired materials to allow signals to pass therethrough to and from the antenna assembly 100.

**[0139]** As shown in Figures 47 and 48, the nozzle cap housing 4130 can further comprise an inner cover 4710, which can be configured to protect the PCB 4320 and an acoustic sensor 5010 (shown in Figure 50). The inner cover 4710 can define an access port 4720 which can be used to connect to the PCB 4320 for purposes such as to calibrate the acoustic sensor 5010 or install software. The inner cover 4710 is held in place by a pair of inner cover fasteners 4712 which engage a pair of inner cover fastener holes 4912 (shown in Figure 49). The nozzle cap housing 4130 can also define threaded strap mounting holes 4714 which are configured for mounting a strap (not shown) which secures the capacitors 4340 and the batteries 4330 in place.

**[0140]** As shown in Figures 48–50, the nozzle cap housing 4130 can define a port 4810 positioned on the antenna mounting surface 4134. When assembled, the port 4810 can be positioned beneath the antenna assembly 100 and the antenna cover 4120. As shown in Figure 48, the port 4810 can define a bore 4812 and a port shoulder 4814. In some aspects, a sensor such as a Reed switch 4820 can be mounted in the port 4810. The Reed switch 4820 can be connected to the PCB 4320 by cables (not shown). The inner cover 4710 can further define a second access port 4850 which can provide clearance for the cables connecting the Reed switch 4820 to the PCB 4320. The Reed switch 4820 can provide a mechanism for externally activating and deactivating the nozzle cap assembly 4100 without positioning an externally accessible switch on the nozzle cap assembly 4100. The Reed switch 4820 can be activated by exposing the nozzle cap assembly 4100 to a magnetic field such as waiving a magnet over the installed antenna cover 4120. The ability to activate and deactivate the nozzle cap assembly 4100 externally can be desirable because it can save time for maintenance personnel and can prevent unnecessary wear on the sealing gasket 4210 by reducing the need for access to the interior cavity 4310. The absence of an externally accessible switch can be desirable because it can prevent tampering with the device and can make the nozzle cap assembly 4100 less distinguishable from a standard version of a nozzle cap 3900.

**[0141]** The port 4810 can also provide a conduit for the cables (not shown) connecting the antenna assembly 100 to the PCB 4320. As shown in Figure 49, the port 4810 can be plugged with potting 4910. The potting 4910 is a material which can be applied around the Reed switch 4820 as well as the cables (not shown) connecting the Reed switch 4820 and an antenna

assembly 100 to the PCB 4320. The material can then harden or dry, and the potting 4910 can secure the Reed switch 4910 and cables in place while sealing the port 4810 from the elements. A tool that engages the port shoulder 4814 and the bore 4812 can be used to position the Reed switch 4820 when the potting 4910 is applied to the port 4810. The potting 4910, the sealing gasket 4210, and the nozzle cap cover 4110 together can seal the interior cavity 4310 of the nozzle cap housing 4130 to prevent unwanted elements such as water or dust from contaminating the electronics. In some aspects, a part or an entirety of the interior cavity 4310 of the nozzle cap housing 4130 may be potted to protect the electronics. In some aspects in which the interior cavity 4310 is potted, a void can be preserved around the acoustic sensor 5010 to prevent contact with the potting. In some aspects, polyurethane can be used as a potting material.

**[0142]** In one aspect, as shown in Figure 50, the acoustic sensor 5010 can be mounted to the nozzle cap housing 4130. In some aspects, the acoustic sensor can be mounted by a threaded connection. The PCB 4320 can be mounted on a plurality of standoffs 5021. The PCB 4320 can further comprise a networking board 5020 configured to perform functions including but not limited to processing, sending signals to the antenna assembly, and receiving signals from the antenna assembly. The PCB 4320 can further comprise a sensor board 5030 which can be connected to the acoustic sensor 5010 or any other sensors and can perform functions including but not limited to processing the signal received from the acoustic sensor 5010.

**[0143]** In use, a sensor, such as the acoustic sensor 5010, can detect phenomena such as vibrations or sound from the hydrant 3600 and a connected fluid system. In some aspects, the fluid system can comprise a water main. The sensor can transmit a signal to the sensor board 5030, where the data can be processed to determine if the vibrations or sounds are indicative of a potential leak in the water main. The data can then be processed by the networking board 5020 and wirelessly transmitted by the antenna assembly 100. The data transmitted in the signal can indicate the presence of a detected leak. A receiving device can wirelessly receive this signal, thereby allowing the hydrant and water main to be remotely monitored for leaks. In some aspects, the sensor can collect data for a parameter of the fluid system such as pressure, temperature, acidity (pH), chemical content, flow rate or other measurable conditions. The collected data for the parameter could then be transmitted wirelessly with the networking board 5020 and the antenna assembly 100.

**[0144]** In one exemplary aspect, a nozzle cap assembly can comprise a nozzle cap housing configured to mount on a hydrant, a nozzle cap cover mounted on the nozzle cap housing, an antenna cover positioned on the nozzle cap housing and secured by the nozzle cap cover, and

the nozzle cap housing the antenna cover, and the nozzle cap cover defining an antenna cover cavity, and an antenna assembly positioned in the antenna cover cavity. In a further exemplary aspect, the nozzle cap housing can define an antenna mounting surface and the antenna cover can define an inner surface, and the antenna mounting surface of the nozzle cap housing, the inner surface of the antenna cover, and the antenna assembly can define a curved shape. In a further exemplary aspect, the curved shape of the antenna mounting surface and the antenna cover can be frustoconical. In a further exemplary aspect, the antenna assembly can comprise a first antenna structure and a second antenna structure, the first antenna structure configured to transmit over a first set of frequency bands, and the second antenna structure configured to transmit over a second set of frequency bands. In a further exemplary aspect, the nozzle cap housing can further comprise a portion of internal threading configured to secure the nozzle cap housing to the hydrant. In a further exemplary aspect, the nozzle cap housing can define a lower rim distal from the nozzle cap cover, the antenna cover securely positioned between the lower rim and the nozzle cap cover.

**[0145]** In a further exemplary aspect the nozzle cap cover can cover an opening defined by the nozzle cap housing, the nozzle cap cover and the nozzle cap housing defining an interior cavity. In a further exemplary aspect, the nozzle cap housing can define a port extending from the interior cavity through the nozzle cap housing to an exterior of the nozzle cap housing. In a further exemplary aspect, the nozzle cap assembly can further comprise a Reed switch positioned within the port. In a further exemplary aspect, the Reed switch can be secured within the port by potting, the potting sealing the port. In a further exemplary aspect, the nozzle cap assembly can further comprise a PCB positioned within the interior cavity and operably connected to the antenna assembly. In a further exemplary aspect, the nozzle cap assembly can further comprise a sensor operably connected to the PCB. In a further exemplary aspect, the nozzle cap assembly can further comprise an inner cover positioned within the interior cavity and mounted to the nozzle cap housing, the PCB positioned within the inner cover.

**[0146]** In another exemplary aspect, a method for monitoring for a parameter in a fluid system can comprise mounting a sensing node on the nozzle of a hydrant connected in fluid communication with the fluid system, the sensing node further comprising a nozzle cap housing, a nozzle cap cover mounted on the nozzle cap housing, the nozzle cap cover and the nozzle cap housing defining an interior cavity, an antenna cover positioned on the nozzle cap housing and secured by the nozzle cap cover, the nozzle cap housing, the antenna cover, and the nozzle cap cover defining an antenna cover cavity, a sensor mounted within the interior cavity and configured to collect data for the parameter, and an antenna assembly positioned in the

antenna cover cavity and configured to transmit a signal carrying data gathered by the sensor, activating the sensing node, gathering data of the parameter with the sensor, and transmitting the data collected by the sensor with the antenna assembly. In a further exemplary aspect, the sensing node can further comprise a Reed switch configured to activate the sensing node when exposed to a magnetic field. In a further exemplary aspect, the antenna assembly can comprise a first antenna structure and a second antenna structure, the first antenna structure configured to transmit over a first set of frequency bands, and the second antenna structure configured to transmit over a second set of frequency bands.

**[0147]** In another exemplary aspect, a smart fluid system can comprise a fluid system, a hydrant connected in fluid communication to the fluid system, the hydrant comprising a nozzle, a sensing node mounted on the nozzle of the hydrant, the sensing node comprising a nozzle cap housing, a nozzle cap cover attached to the nozzle cap housing, the nozzle cap cover and the nozzle cap housing defining an interior cavity, an antenna cover mounted on the nozzle cap housing and secured between the nozzle cap housing and the nozzle cap cover, the nozzle cap housing, the nozzle cap cover, and the antenna cover defining an antenna cover cavity, a sensor positioned within the interior cavity, the sensor configured to collect data for a parameter of the fluid system, and an antenna assembly mounted to the nozzle cap housing, the antenna assembly positioned within the antenna cover cavity, the antenna assembly configured to transmit the data collected by the sensor. In a further exemplary aspect, the antenna assembly, the antenna cover, and an antenna mounting surface of the nozzle cap housing can each define a curved shape. In a further exemplary aspect, the sensing node can be an acoustic node configured to detect a leak in the distribution main. In a further exemplary aspect, the nozzle cap housing can define a lower rim distal from the nozzle cap cover, the antenna cover positioned on the nozzle cap housing and secured between the lower rim and the nozzle cap cover.

**[0148]** In another exemplary aspect, a nozzle cap assembly can comprise a nozzle cap housing and an antenna assembly mounted to the nozzle cap housing.

**[0149]** It should be emphasized that the above-described aspects are merely possible examples of implementations, merely set forth for a clear understanding of the principles of the present disclosure. Many variations and modifications can be made to the above-described aspect(s) without departing substantially from the spirit and principles of the present disclosure. All such modifications and variations are intended to be included herein within the scope of the present disclosure, and all possible claims to individual aspects or combinations of elements or steps are intended to be supported by the present disclosure. Moreover, although specific terms are employed herein, as well as in the claims which follow, they are used only in a generic



and descriptive sense, and not for the purposes of limiting the described invention, nor the claims which follow.

## CLAIMS

1. A nozzle cap assembly comprising:

a nozzle cap housing configured to mount on a hydrant, the nozzle cap housing defining an upper rim and a lower rim, the nozzle cap housing defining an interior cavity extending inward from the upper rim toward the lower rim, the nozzle cap housing defining an antenna mounting portion extending from the upper rim toward the lower rim;

an antenna cover mounted on the nozzle cap housing, the antenna cover positioned over at least a portion of the antenna mounting portion, the antenna cover defining an inner cover surface facing the antenna mounting portion, an antenna cover cavity at least partially defined between the inner cover surface and the antenna mounting portion; and

an antenna assembly positioned in the antenna cover cavity, the antenna assembly comprising a printed circuit board ("PCB") and an antenna structure positioned on the PCB, the PCB secured directly against the inner cover surface.
2. The nozzle cap assembly of claim 1, wherein potting is positioned at least partially between the antenna cover and the interior cavity.
3. The nozzle cap assembly of claim 2, wherein the potting is positioned at least partially between the antenna assembly and the interior cavity.
4. The nozzle cap assembly of claim 1, wherein the nozzle cap housing defines a port extending through the antenna mounting portion to the interior cavity, and wherein a cable attached to the antenna assembly extends through the port.
5. The nozzle cap assembly of claim 4, wherein the port is at least partially covered by potting, the potting positioned at least partially between the antenna assembly and the interior cavity.

6. The nozzle cap assembly of claim 1, wherein the PCB is adhered to the inner cover surface.
7. The nozzle cap assembly of claim 1, further comprising a nozzle cap cover attached to the upper rim, the nozzle cap housing defining a shoulder, the antenna cover secured between the nozzle cap cover and the shoulder.
8. The nozzle cap assembly of claim 1, wherein the antenna mounting portion is defined radially inward from the lower rim.
9. A smart fluid system comprising:
  - a fluid system;
  - a hydrant connected in fluid communication to the fluid system, the hydrant comprising a nozzle;
  - a sensing node mounted on the nozzle of the hydrant, the sensing node comprising:
    - a nozzle cap housing defining an upper rim and a lower rim, the nozzle cap housing defining an interior cavity extending inward from the upper rim toward the lower rim, the nozzle cap housing defining an antenna mounting portion extending from the upper rim toward the lower rim;
    - a sensor attached to the nozzle cap housing, the sensor configured to collect data for a parameter of the fluid system;
    - an antenna cover mounted on the nozzle cap housing, the antenna cover positioned over at least a portion of the antenna mounting portion, the antenna cover defining an inner cover surface facing the antenna

mounting portion, an antenna cover cavity at least partially defined between the inner cover surface and the antenna mounting portion; and

an antenna assembly positioned in the antenna cover cavity, the antenna assembly comprising a printed circuit board ("PCB") and an antenna structure positioned on the PCB, the PCB secured directly against the inner cover surface, the antenna assembly configured to transmit the data collected by the sensor.

10. The smart fluid system of claim 9, wherein potting is positioned at least partially between the antenna cover and the interior cavity.
11. The smart fluid system of claim 10, wherein the potting is positioned at least partially between the antenna assembly and the interior cavity.
12. The smart fluid system of claim 9, wherein the nozzle cap housing defines a port extending through the antenna mounting portion to the interior cavity, and wherein a cable attached to the antenna assembly extends through the port.
13. The smart fluid system of claim 12, wherein the port is at least partially covered by potting, the potting positioned at least partially between the antenna assembly and the interior cavity.
14. The smart fluid system of claim 9, wherein the antenna assembly is adhered to the inner cover surface.
15. The smart fluid system of claim 9, further comprising a nozzle cap cover attached to the upper rim, the nozzle cap housing defining a shoulder, the antenna cover secured between the nozzle cap cover and the shoulder.
16. The smart fluid system of claim 9, wherein the antenna mounting portion is defined radially inward from the lower rim.

17. A nozzle cap assembly comprising:

a nozzle cap cover;

a nozzle cap housing defining a first end and a second end, the first end positioned opposite from the second end, the nozzle cap housing comprising:

an upper rim positioned at the first end, the nozzle cap cover mounted on the upper rim;

a divider wall positioned between the first end and the second end, the nozzle cap housing defining an interior cavity extending into the upper rim to the divider wall, the interior cavity extending in a direction from the upper rim towards the second end, the nozzle cap cover enclosing the interior cavity; and

a lower rim positioned at the second end, the nozzle cap housing defining an internally threaded bore extending into the lower rim to the divider wall, the internally threaded bore extending in a direction from the lower rim towards the first end, the divider wall positioned between the upper rim and the lower rim, the divider wall separating the interior cavity from the internally threaded bore, the internally threaded bore configured to mount on a nozzle of a fire hydrant; and

an acoustic sensor positioned within the interior cavity between the divider wall and the upper rim, the acoustic sensor configured to detect vibrations.

18. The nozzle cap assembly of claim 17, wherein a gasket is positioned between the upper rim and the nozzle cap cover; and wherein the gasket forms a seal between the upper rim and the nozzle cap cover.

19. The nozzle cap assembly of claim 17, further comprising at least one battery and a printed circuit board ("PCB"), the at least one battery and the PCB connected in electrical communication with the acoustic sensor.
20. The nozzle cap assembly of claim 17, wherein the divider wall is perpendicular to the internally threaded bore.
21. A nozzle cap assembly comprising:
  - a nozzle cap housing configured to mount on a hydrant, the nozzle cap housing defining an upper rim and a lower rim, the nozzle cap housing defining an interior cavity extending inward from the upper rim toward the lower rim, the nozzle cap housing defining an antenna mounting portion extending from the upper rim toward the lower rim;
  - an antenna cover mounted on the nozzle cap housing, the antenna cover positioned over at least a portion of the antenna mounting portion, the antenna cover defining an inner cover surface facing the antenna mounting portion, an antenna cover cavity at least partially defined between the inner cover surface and the antenna mounting portion;
  - an antenna assembly positioned in the antenna cover cavity, the antenna assembly secured in facing engagement with the inner cover surface; and
  - potting positioned at least partially between the antenna cover and the interior cavity, the potting positioned at least partially between the antenna assembly and the interior cavity.

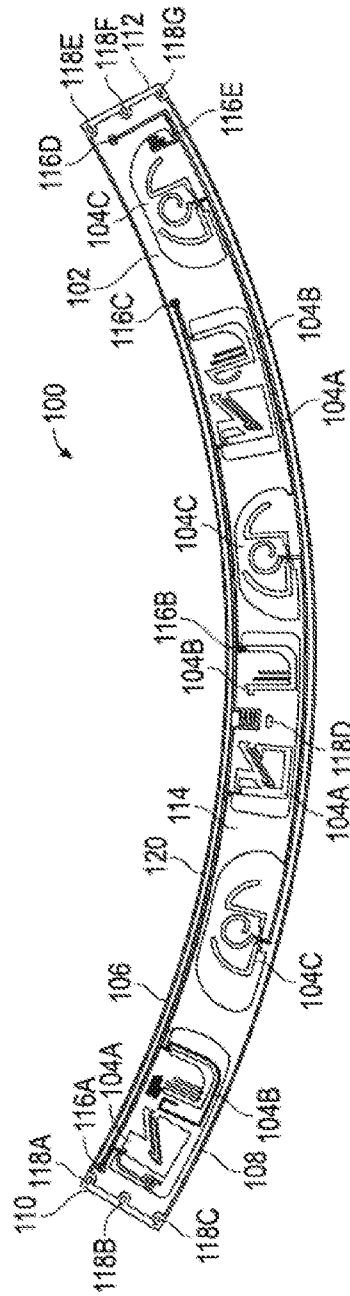


FIG. 1

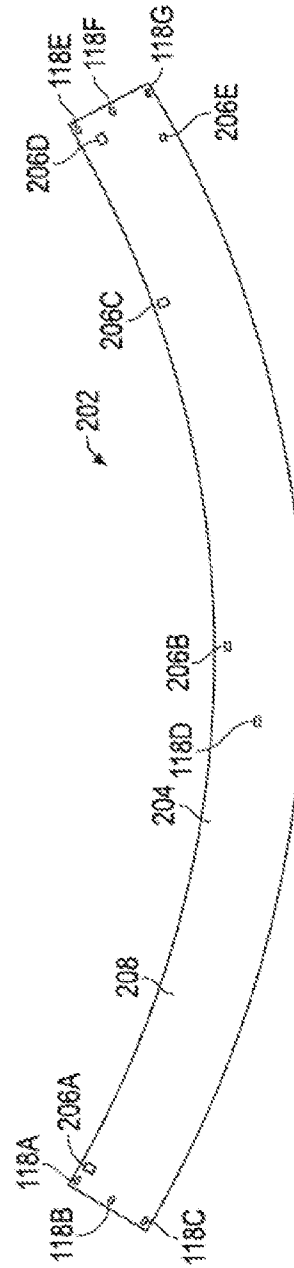
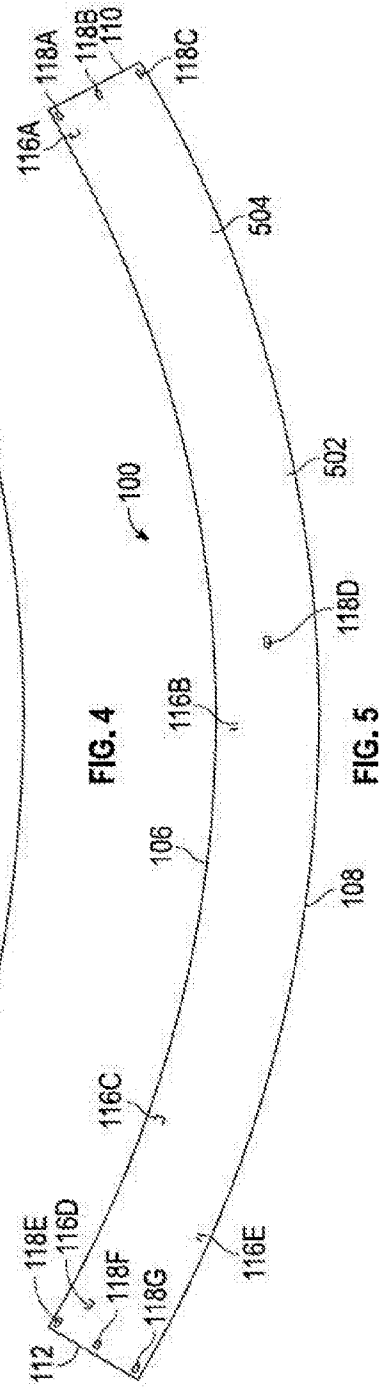
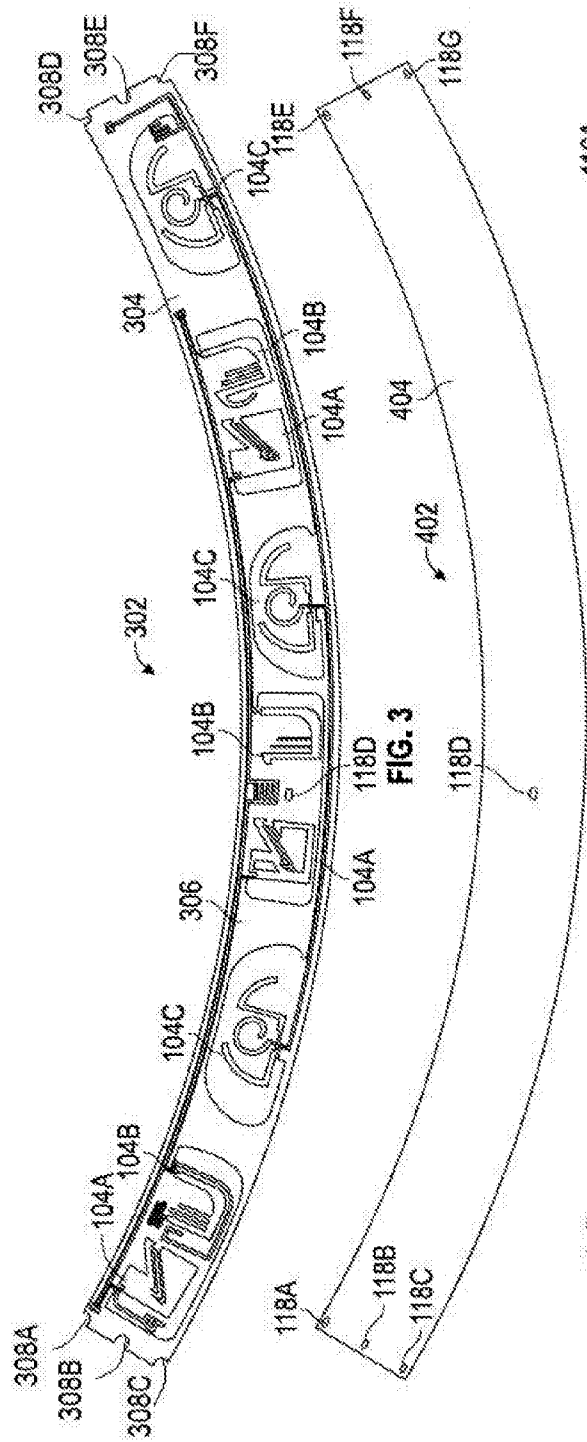


FIG. 2



**FIG. 5**



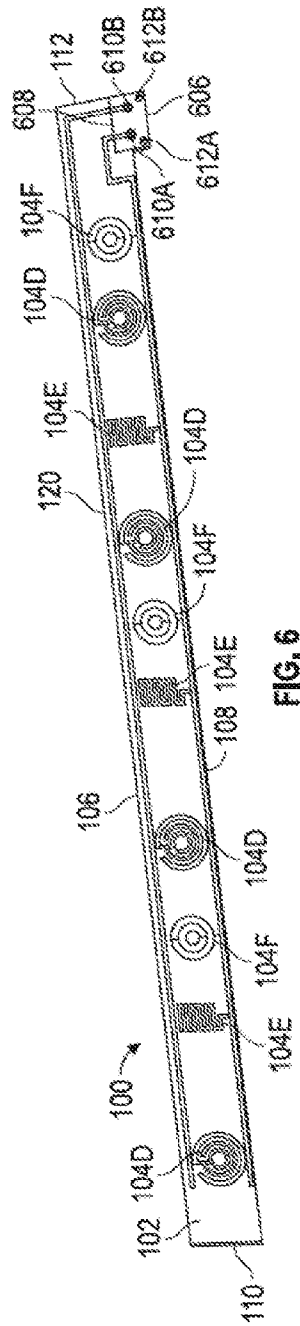


FIG. 6

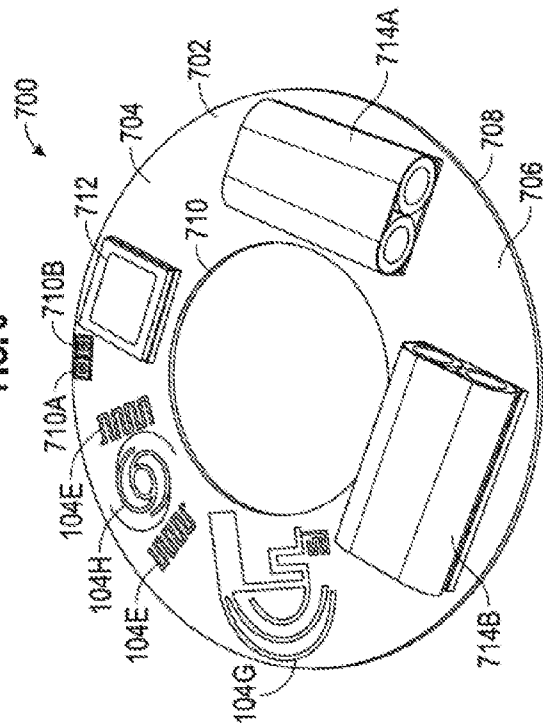
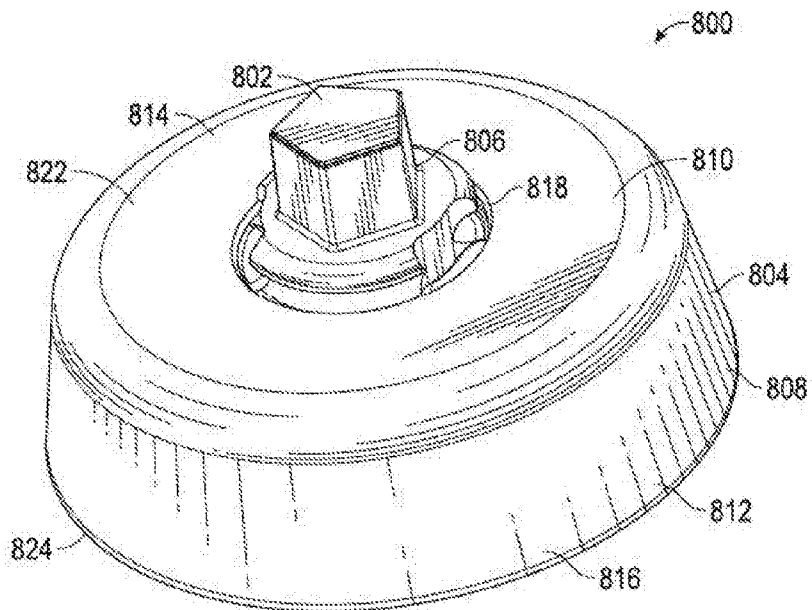
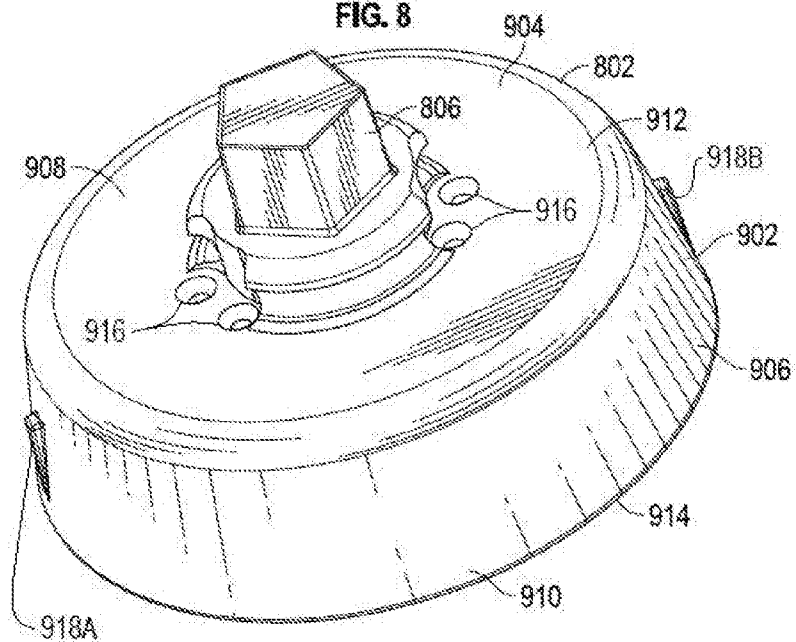


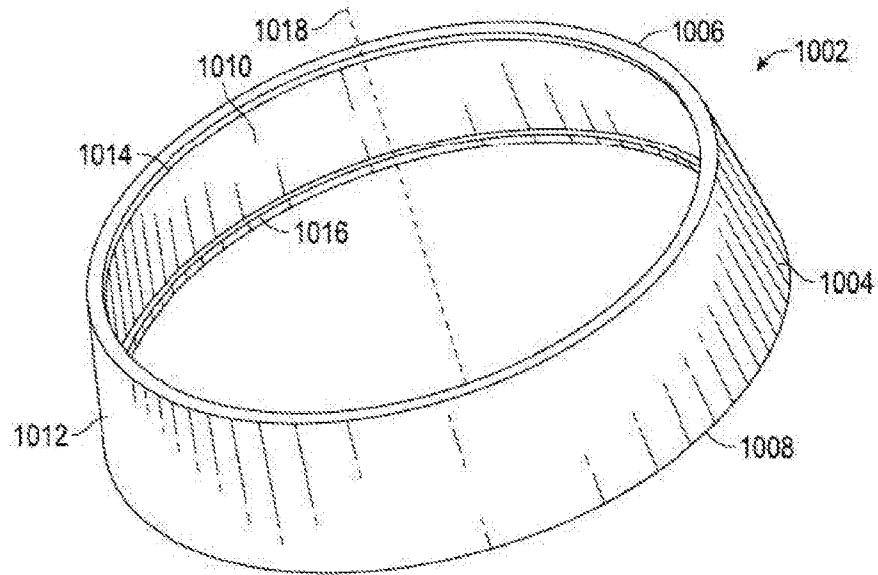
FIG. 7



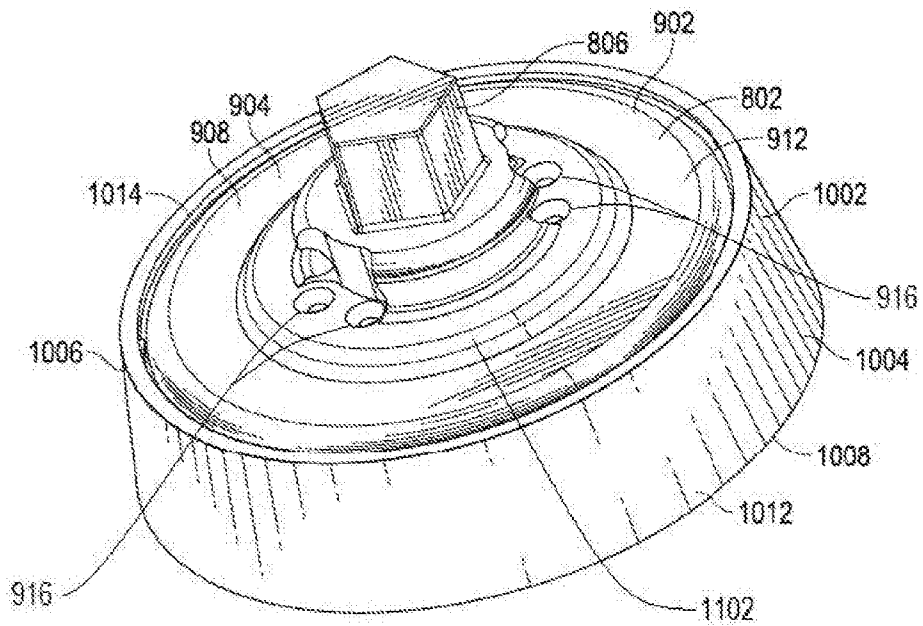
**FIG. 8**



**FIG. 9**



**FIG. 10**



**FIG. 11**

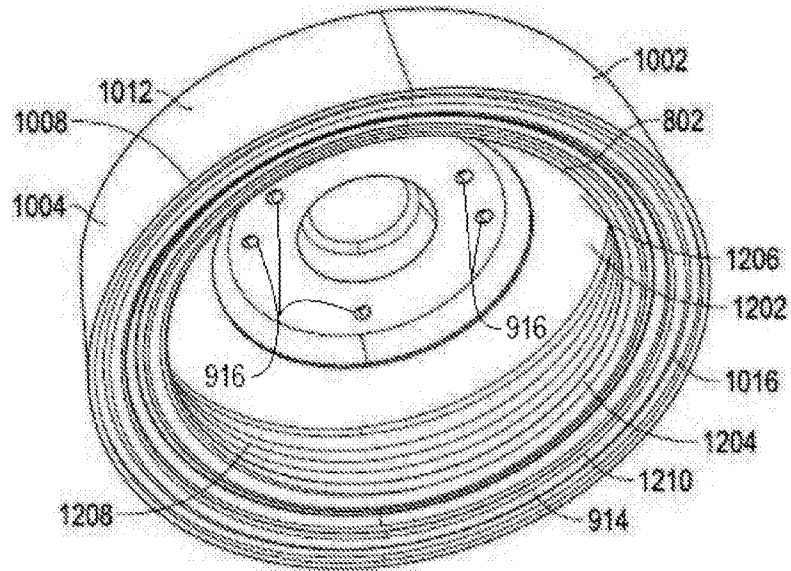


FIG. 12

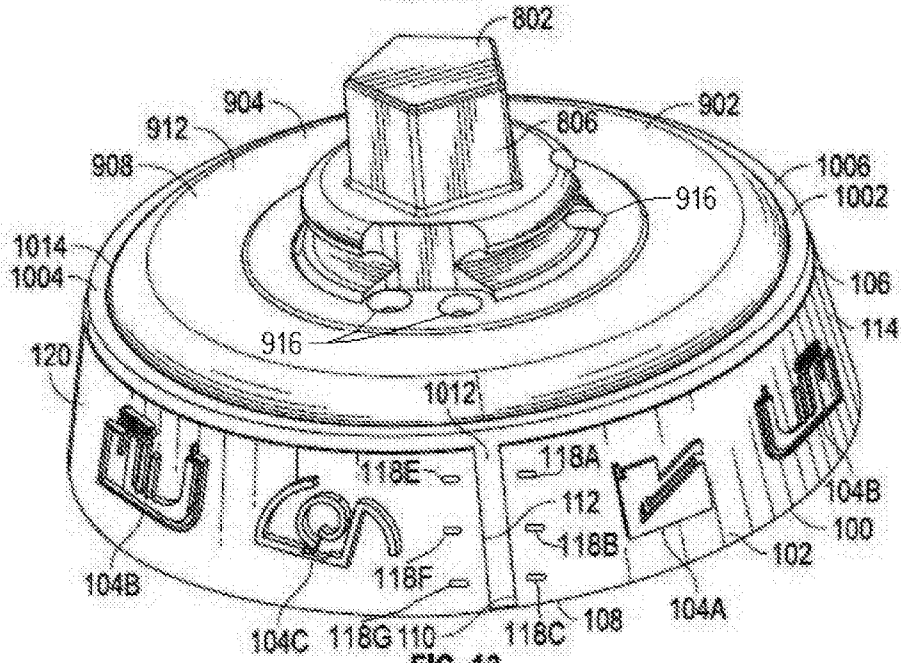


FIG. 13

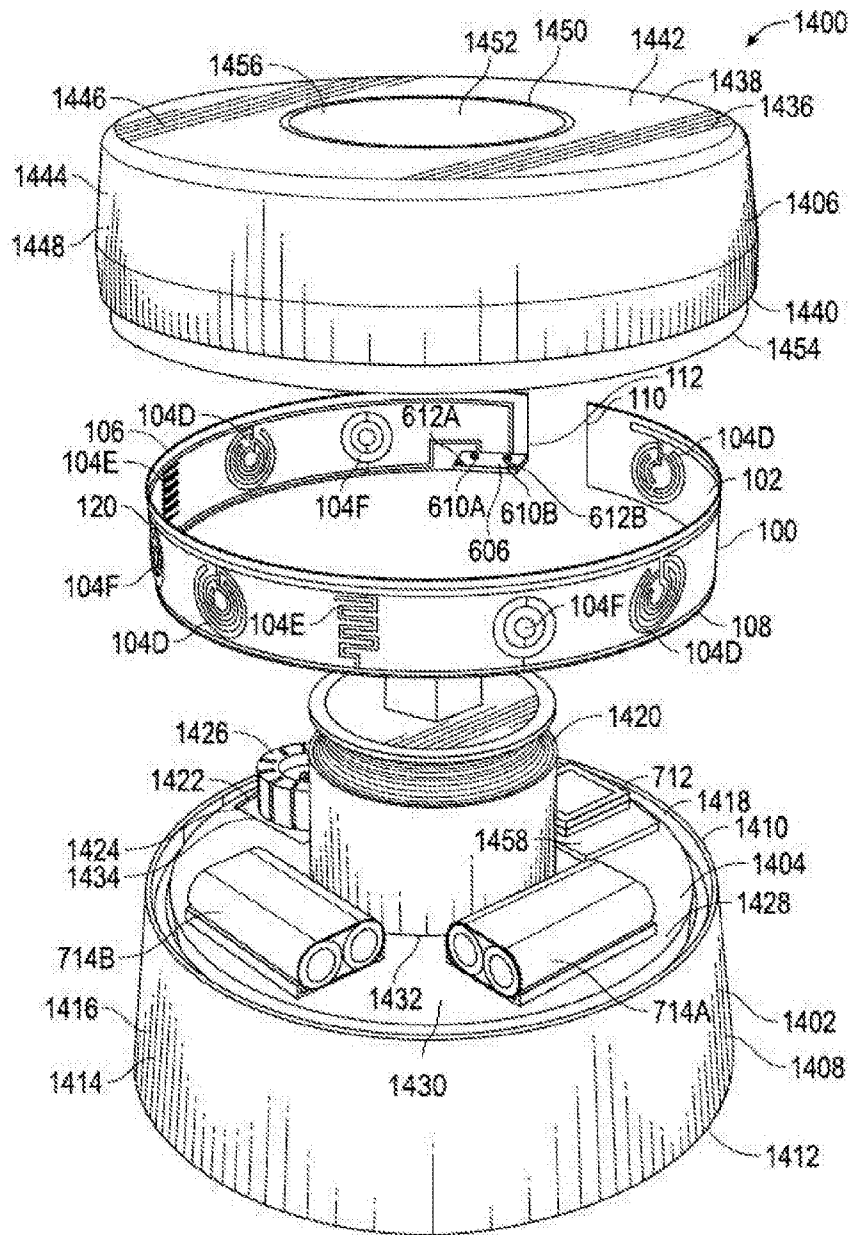


FIG. 14

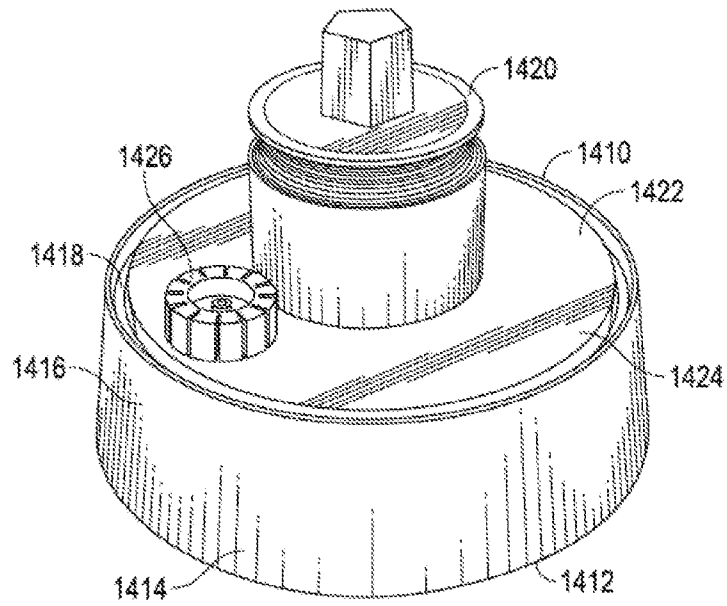


FIG. 15

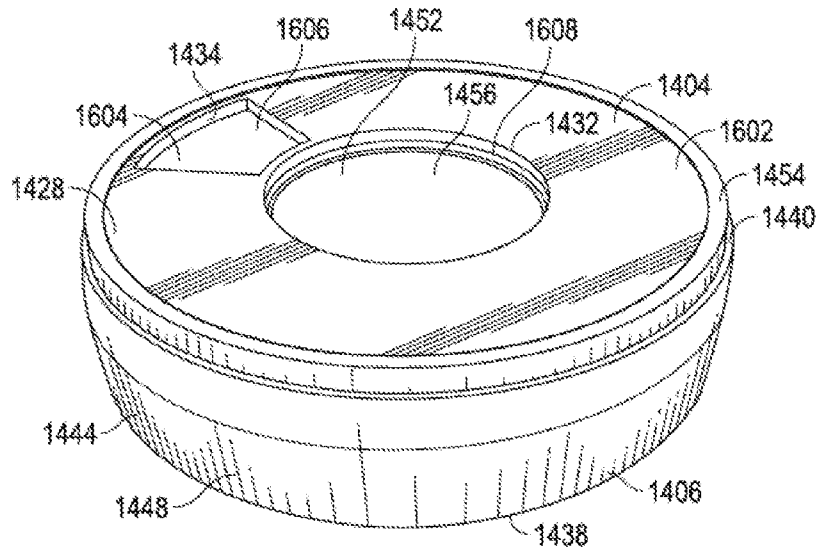
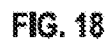
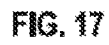


FIG. 16



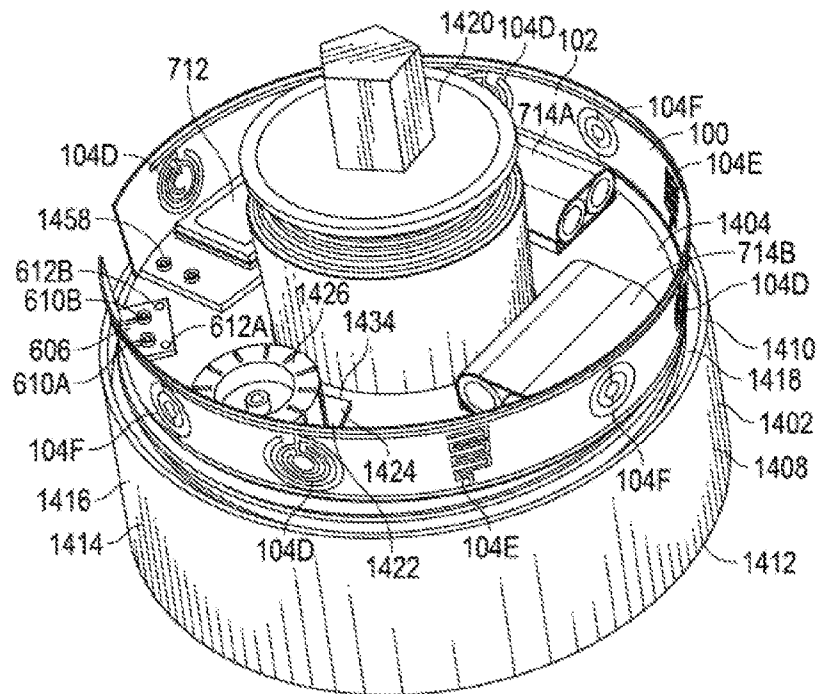


FIG. 19

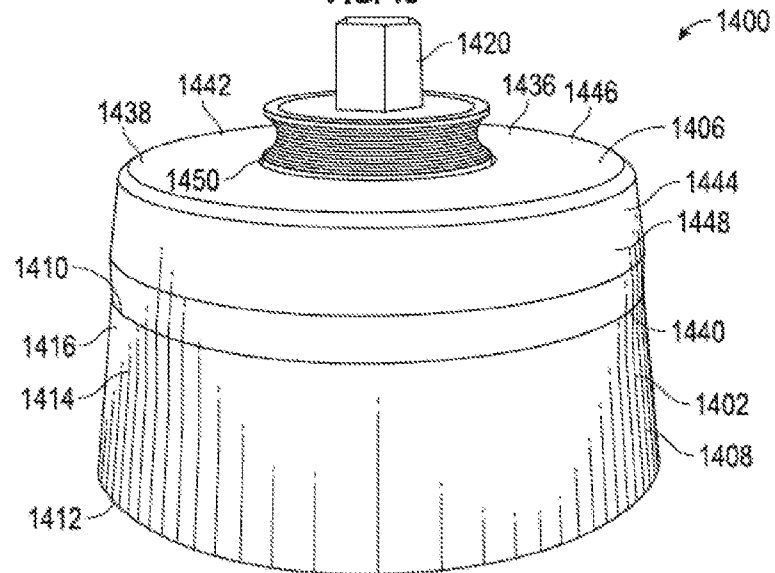


FIG. 20



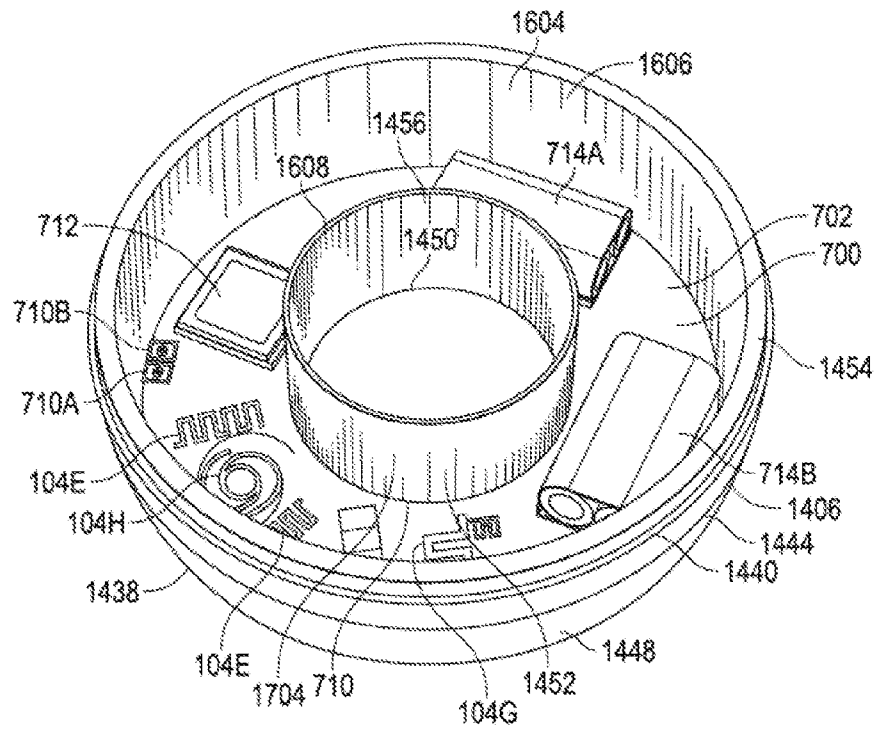


FIG. 21

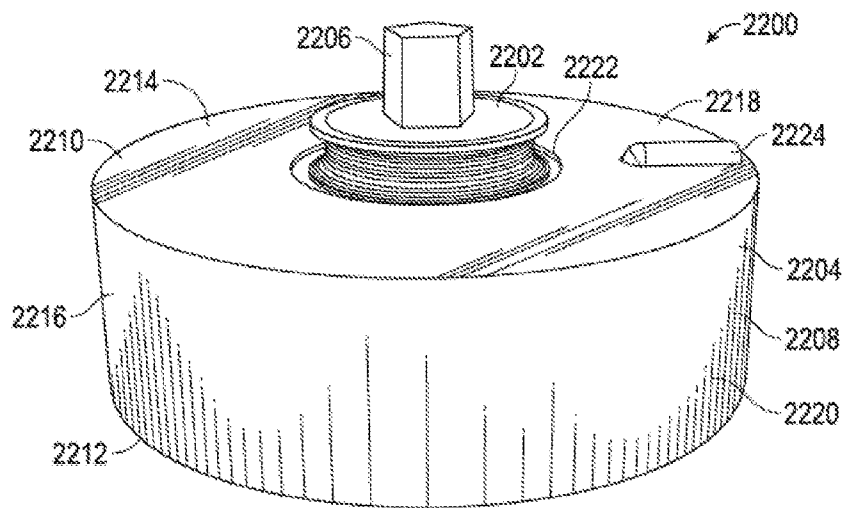


FIG. 22

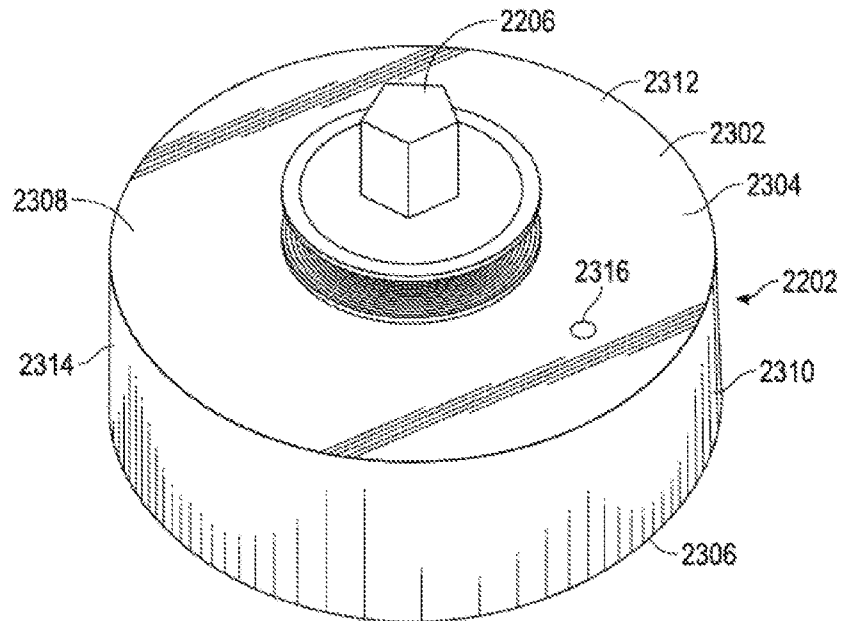


FIG. 23

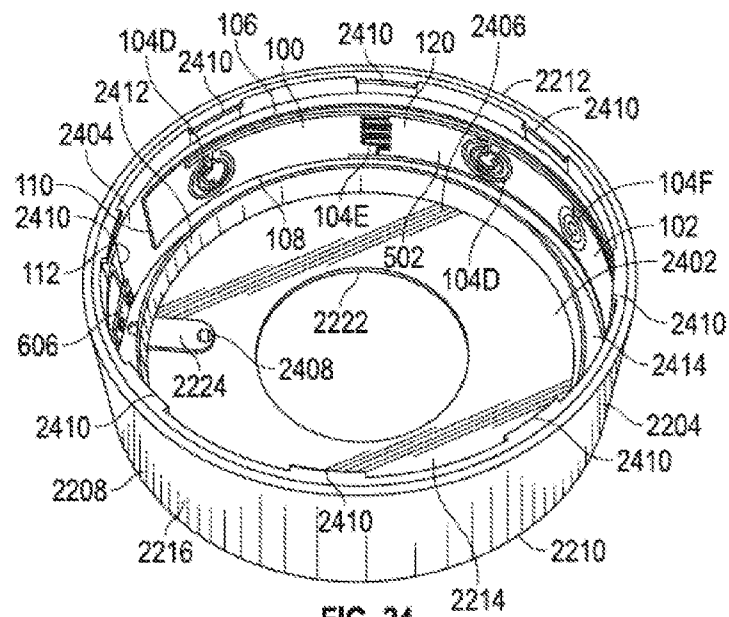


FIG. 24

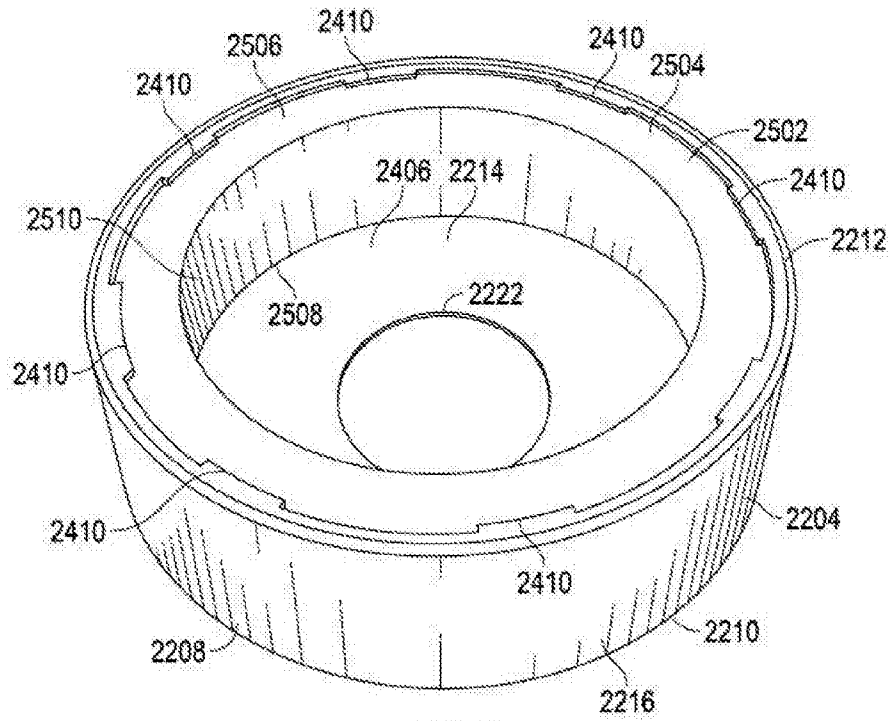


FIG. 25

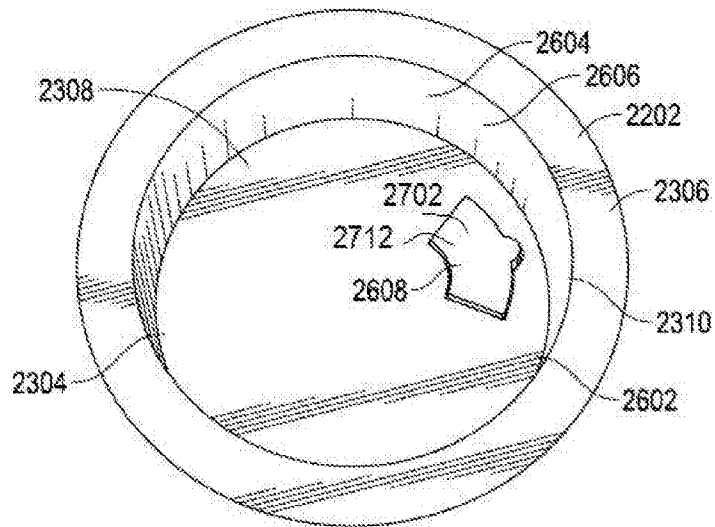
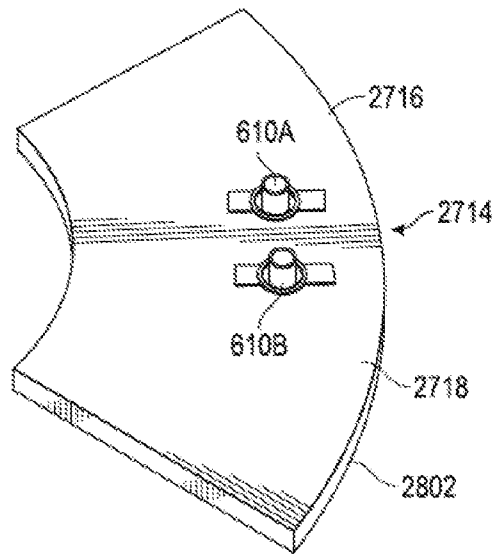
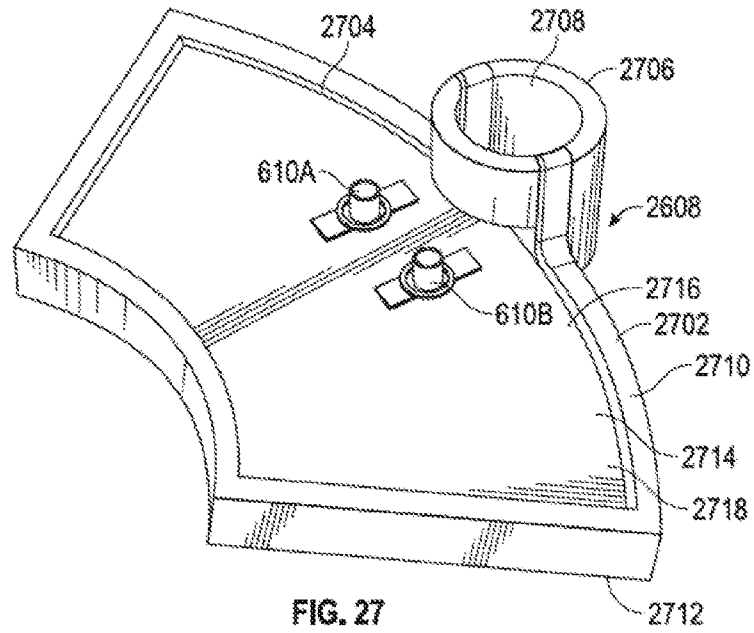


FIG. 26



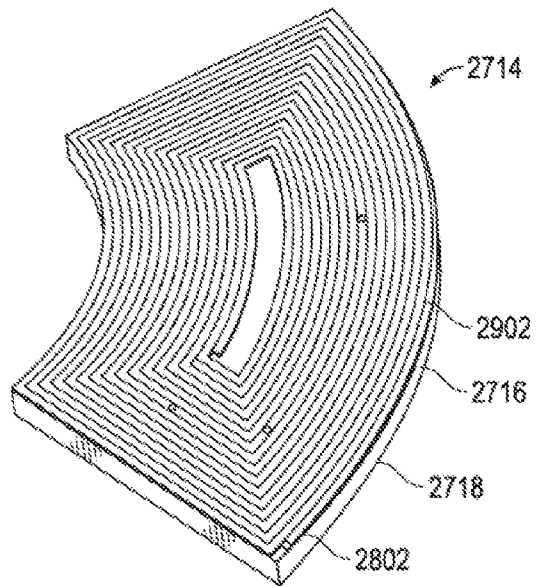


FIG. 29

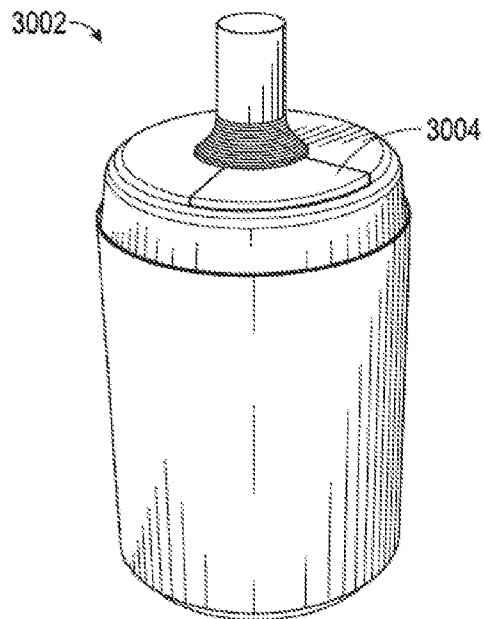


FIG. 30

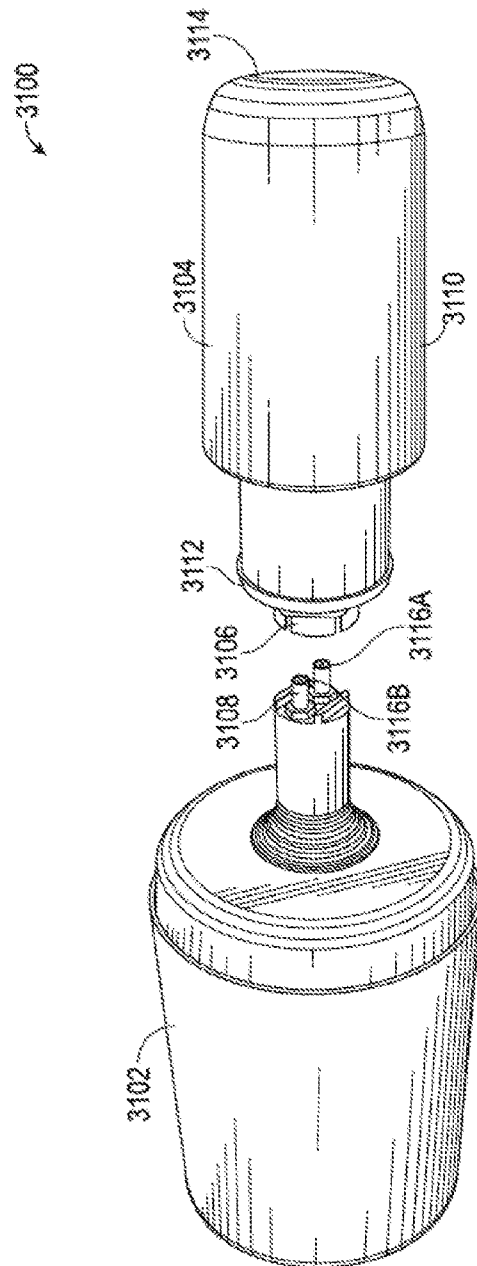


FIG. 31

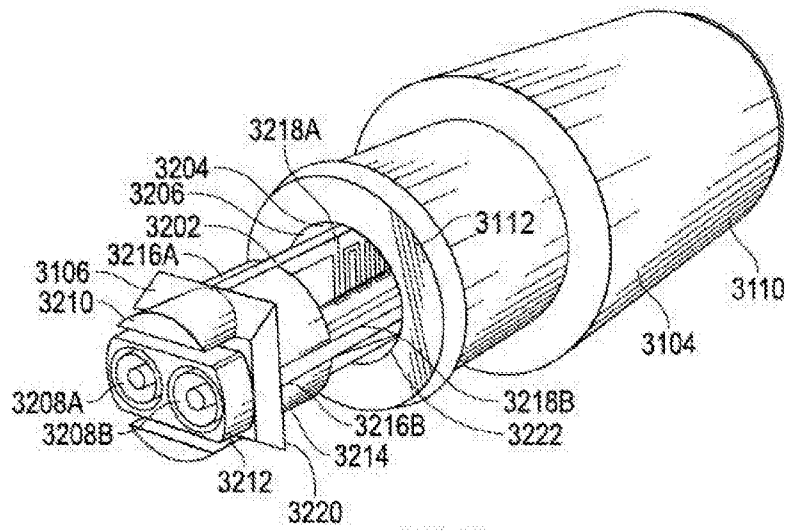


FIG. 32

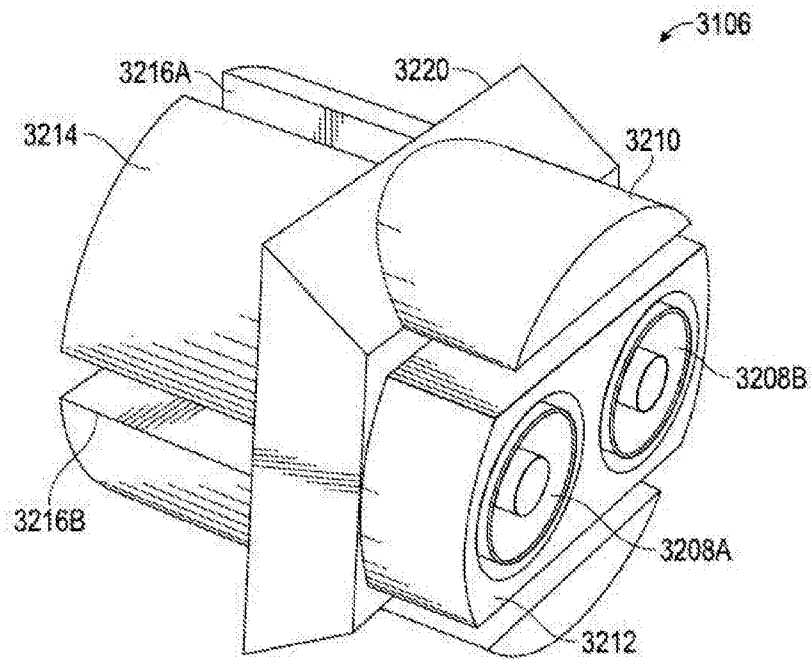


FIG. 33

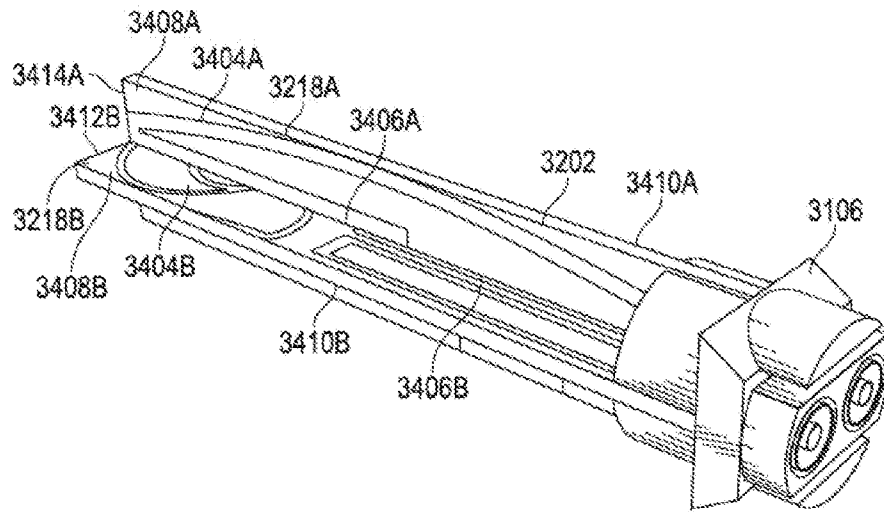


FIG. 34

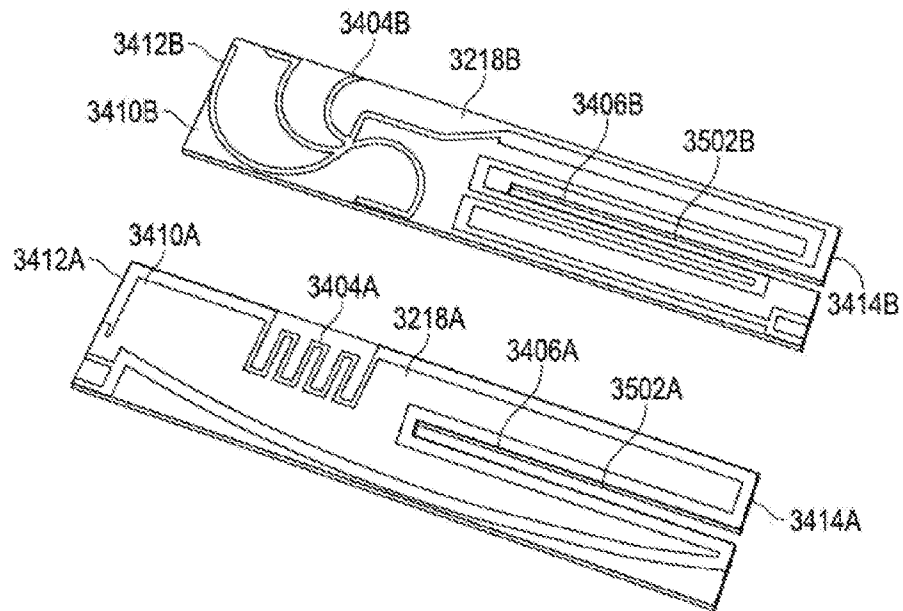
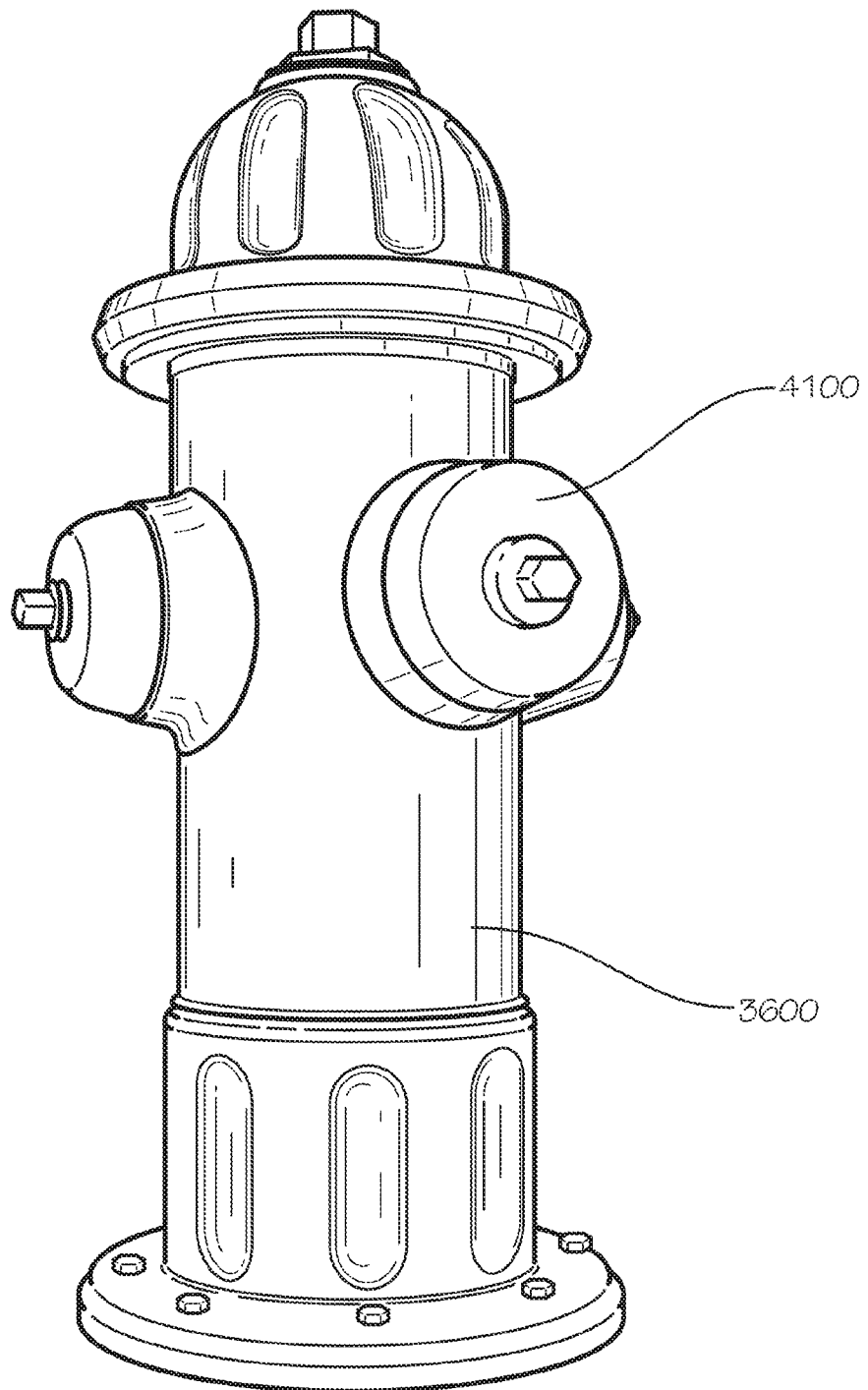


FIG. 35





**FIG. 36**

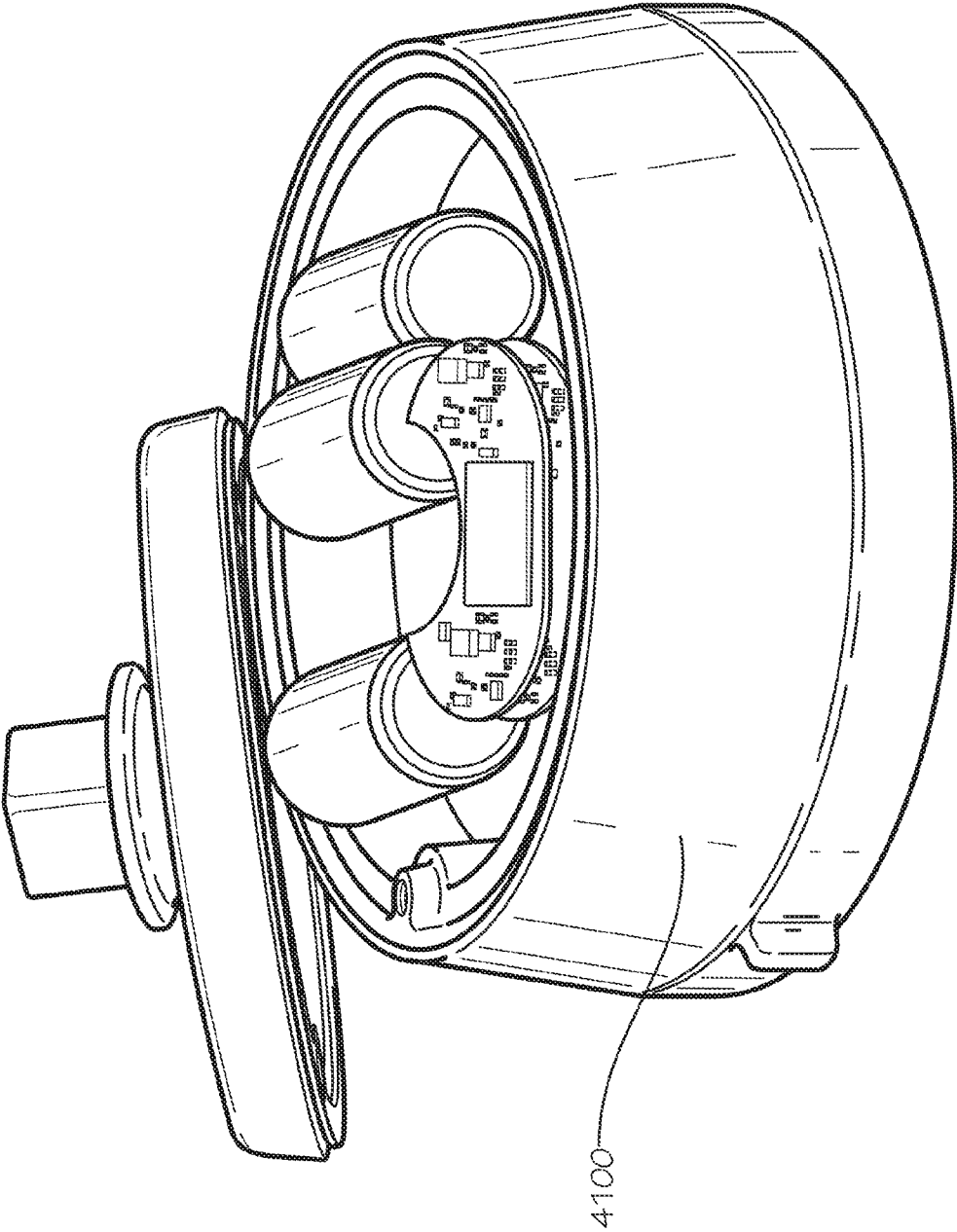
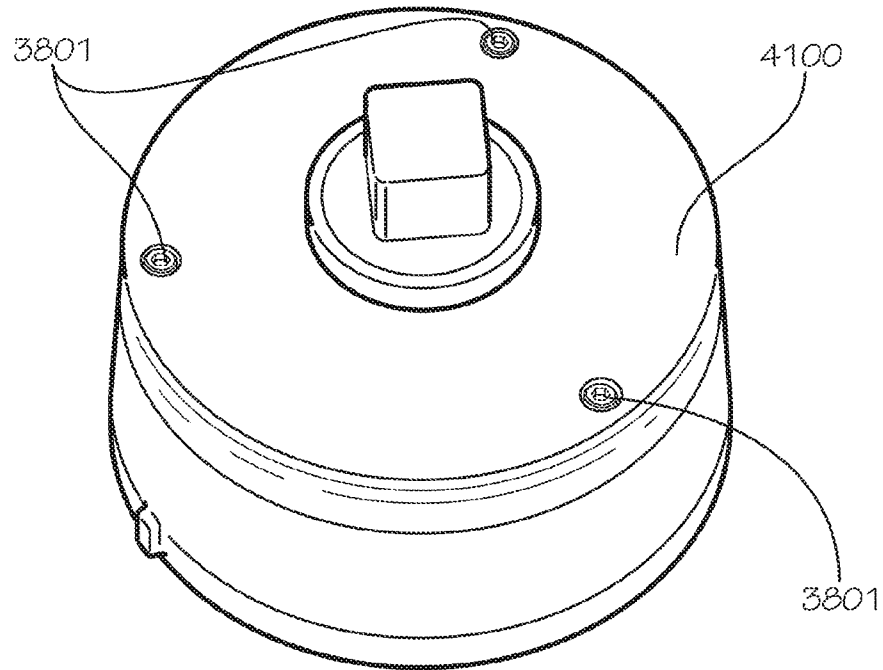
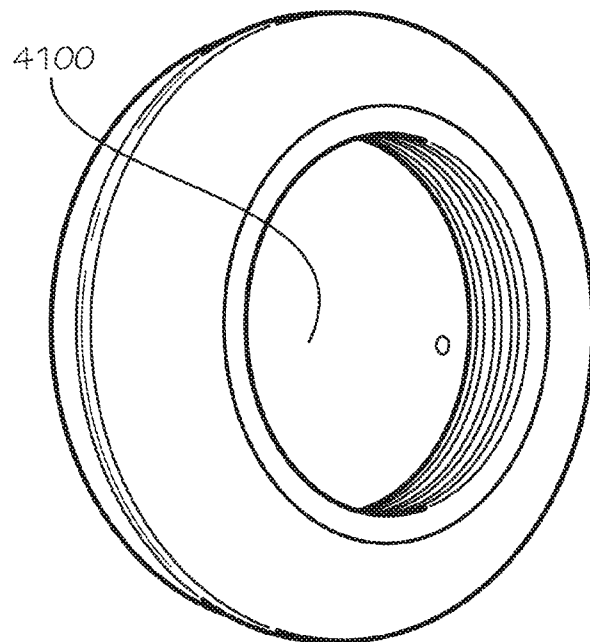


FIG. 37



**FIG. 38A**



**FIG. 38B**

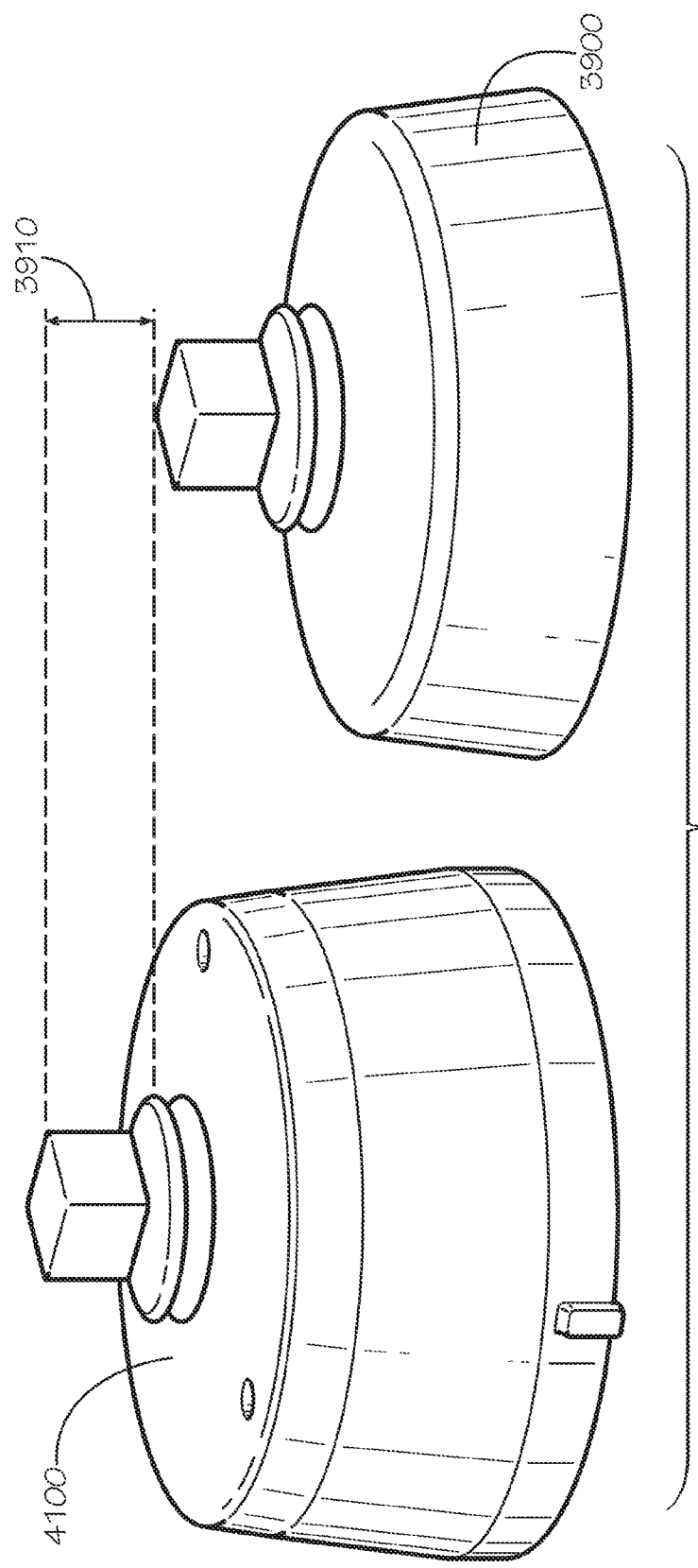


FIG. 39

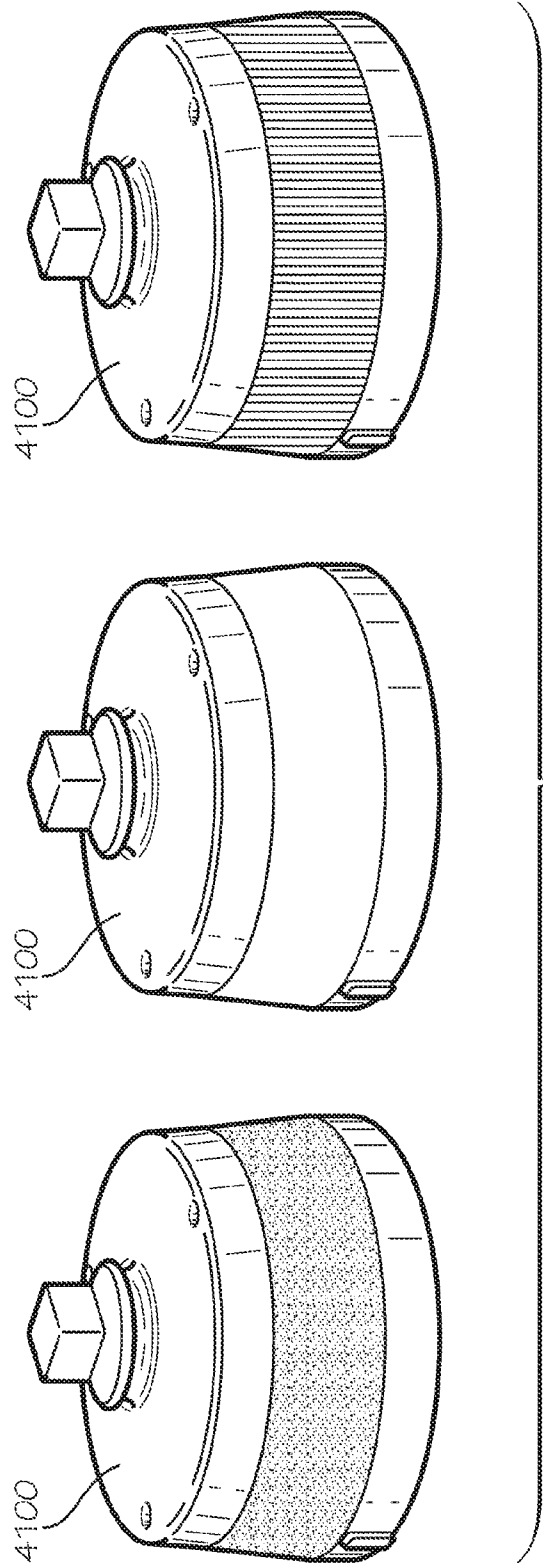
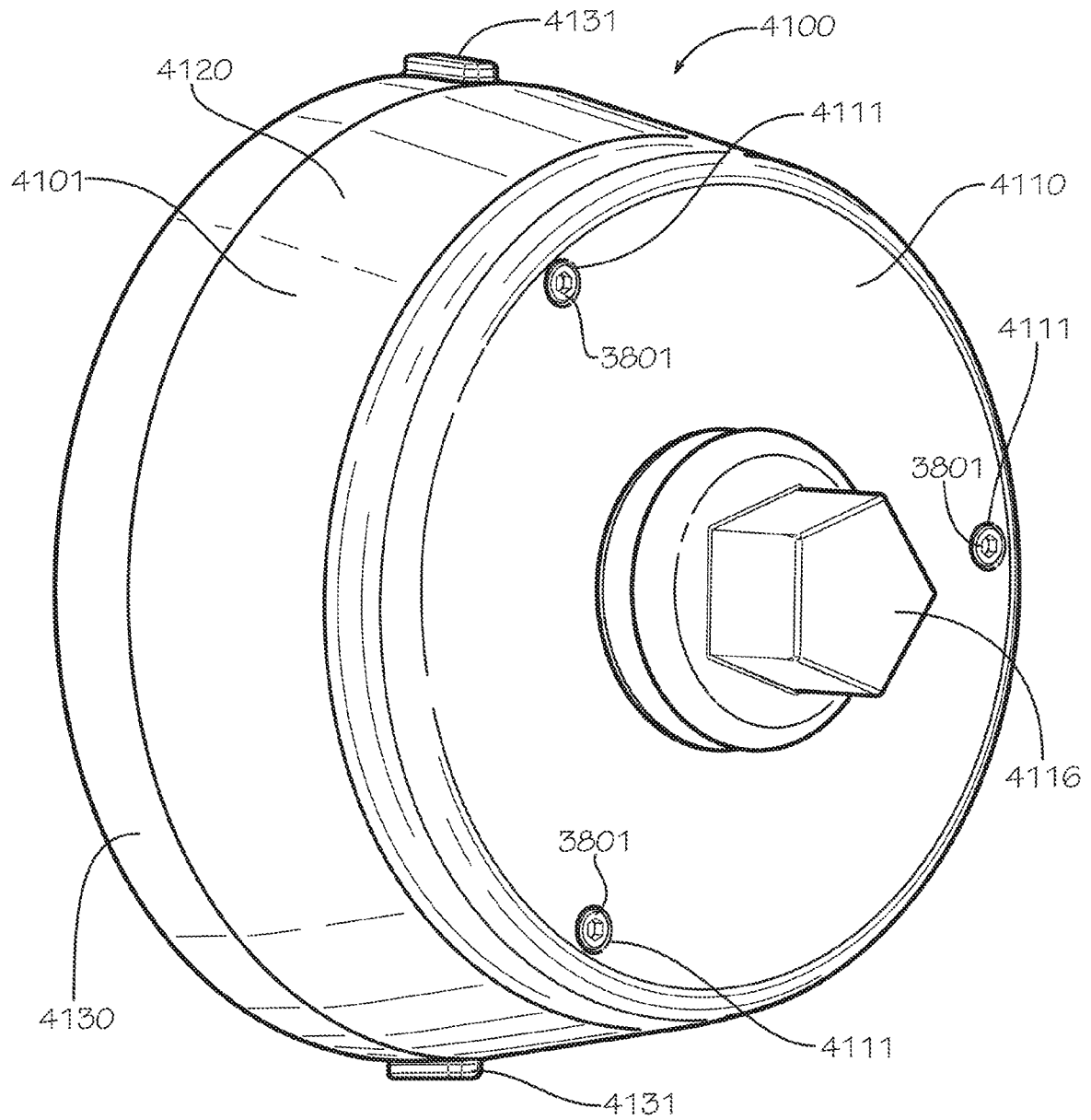
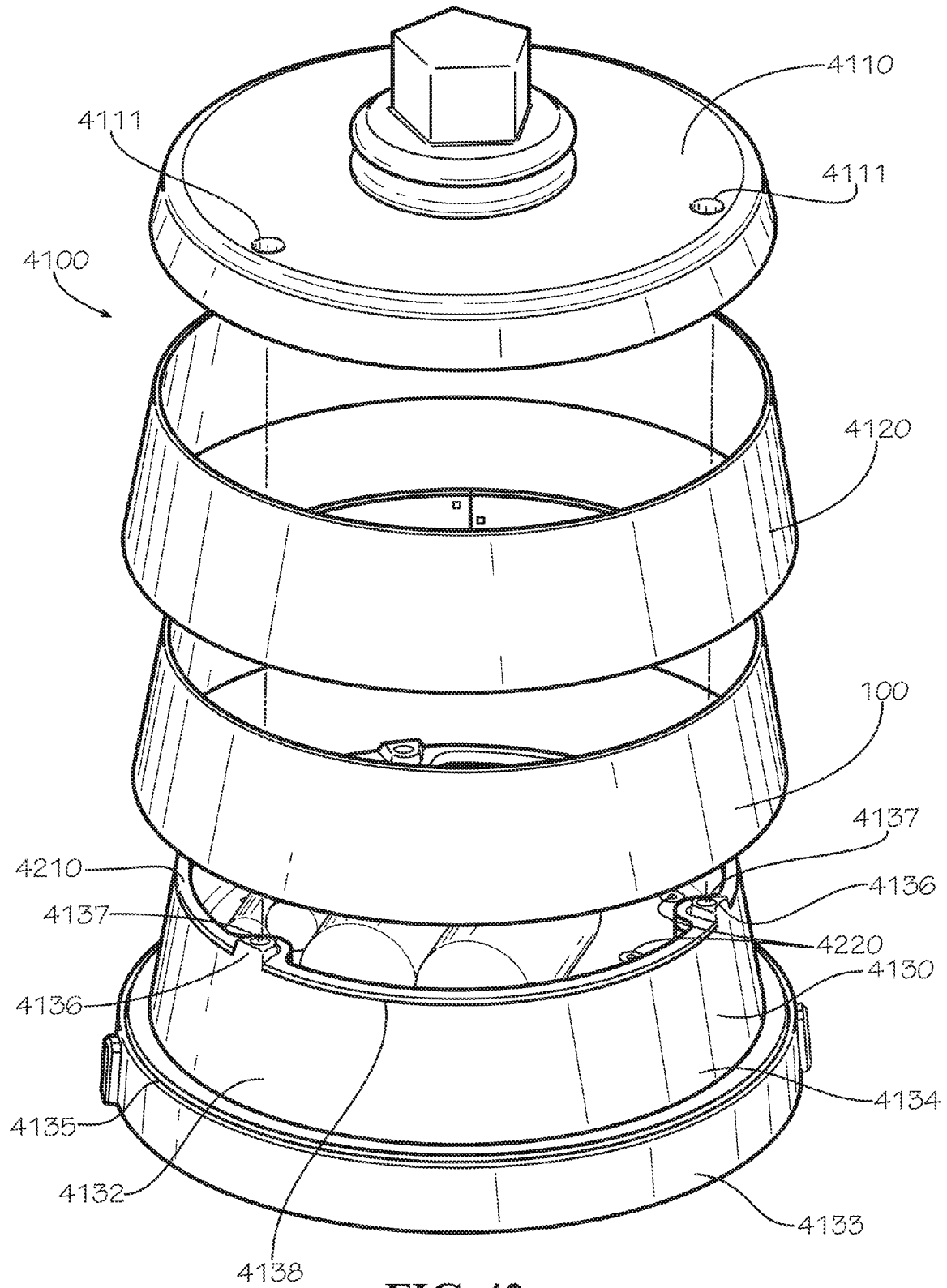


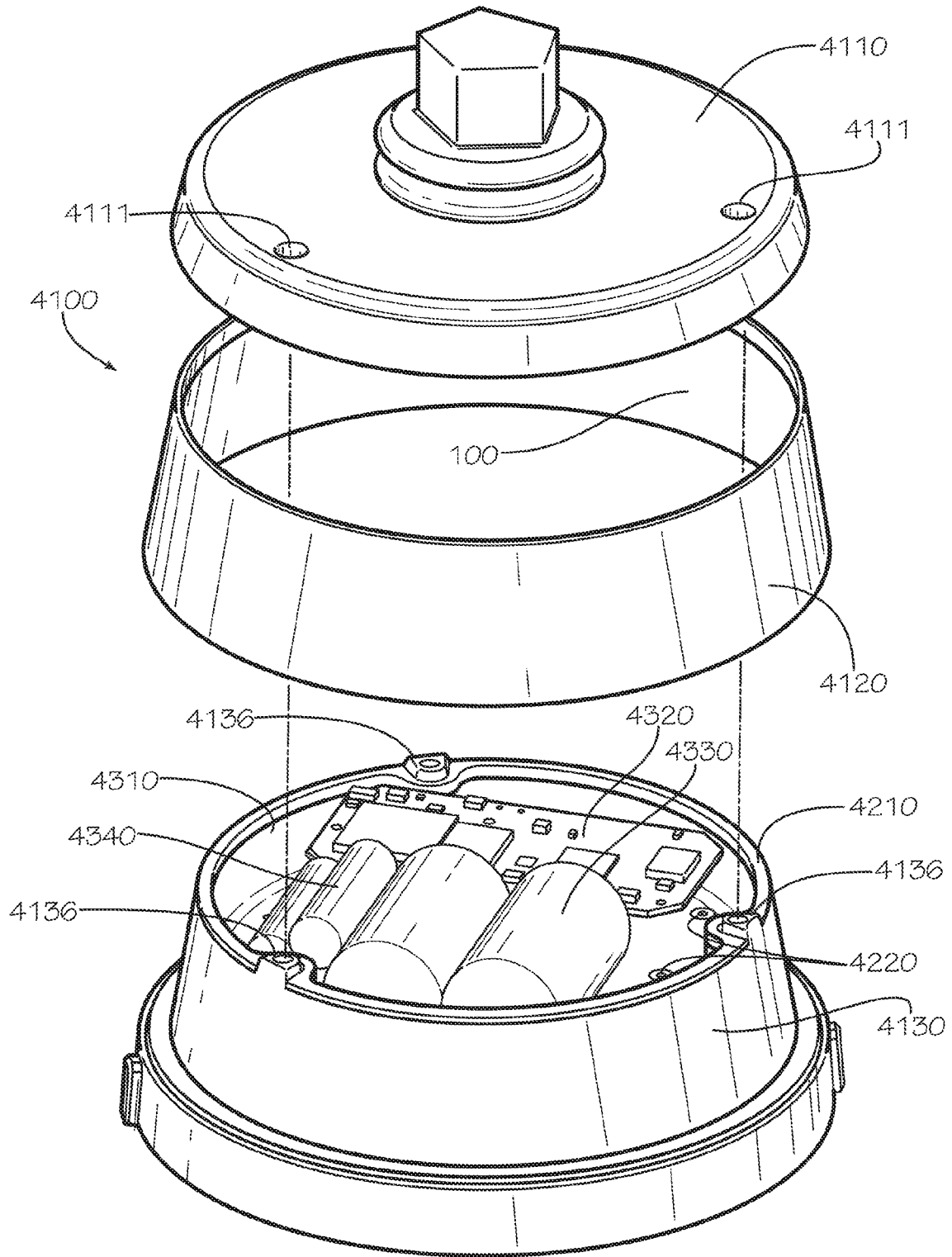
FIG. 40



**FIG. 41**

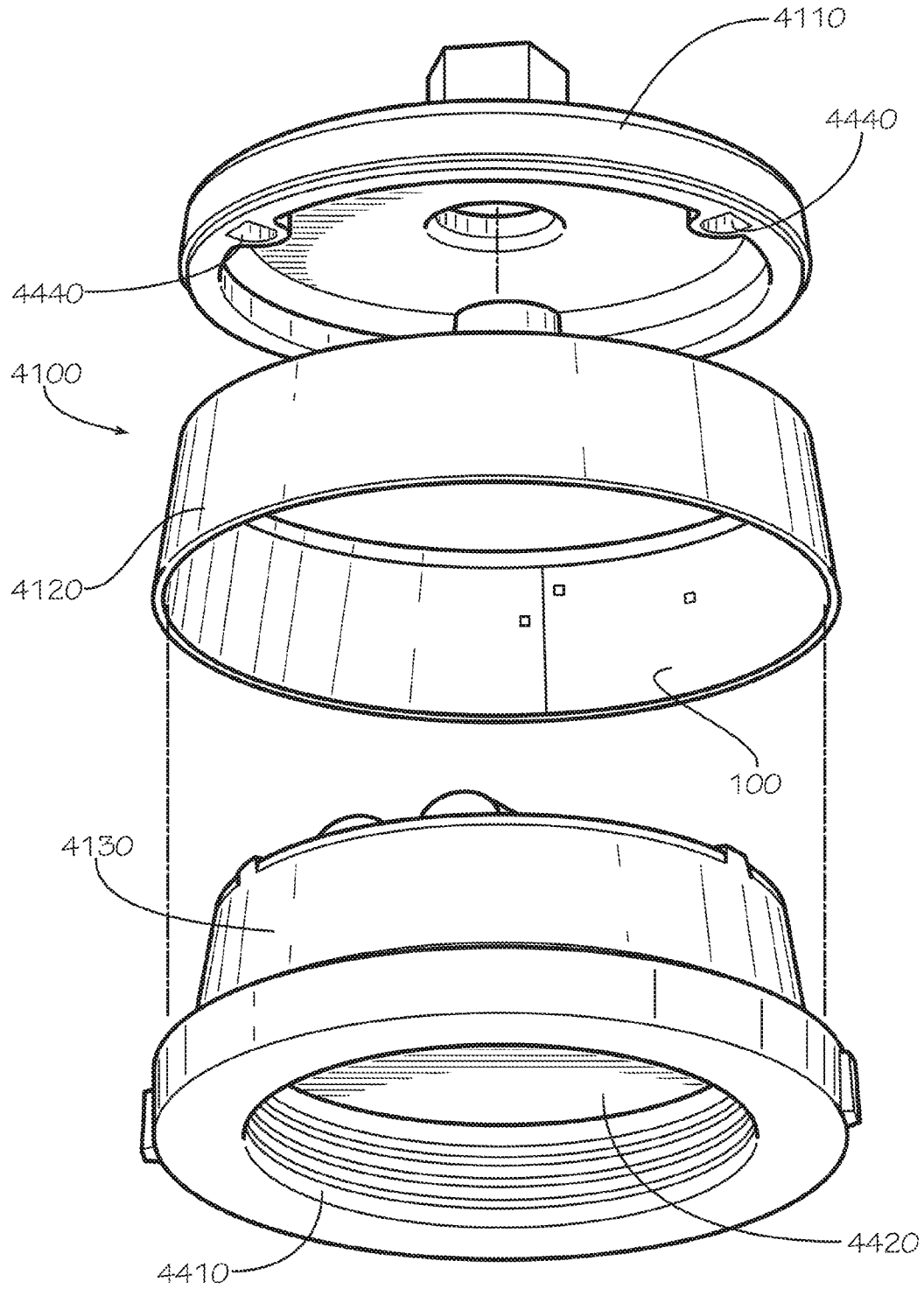


**FIG. 42**

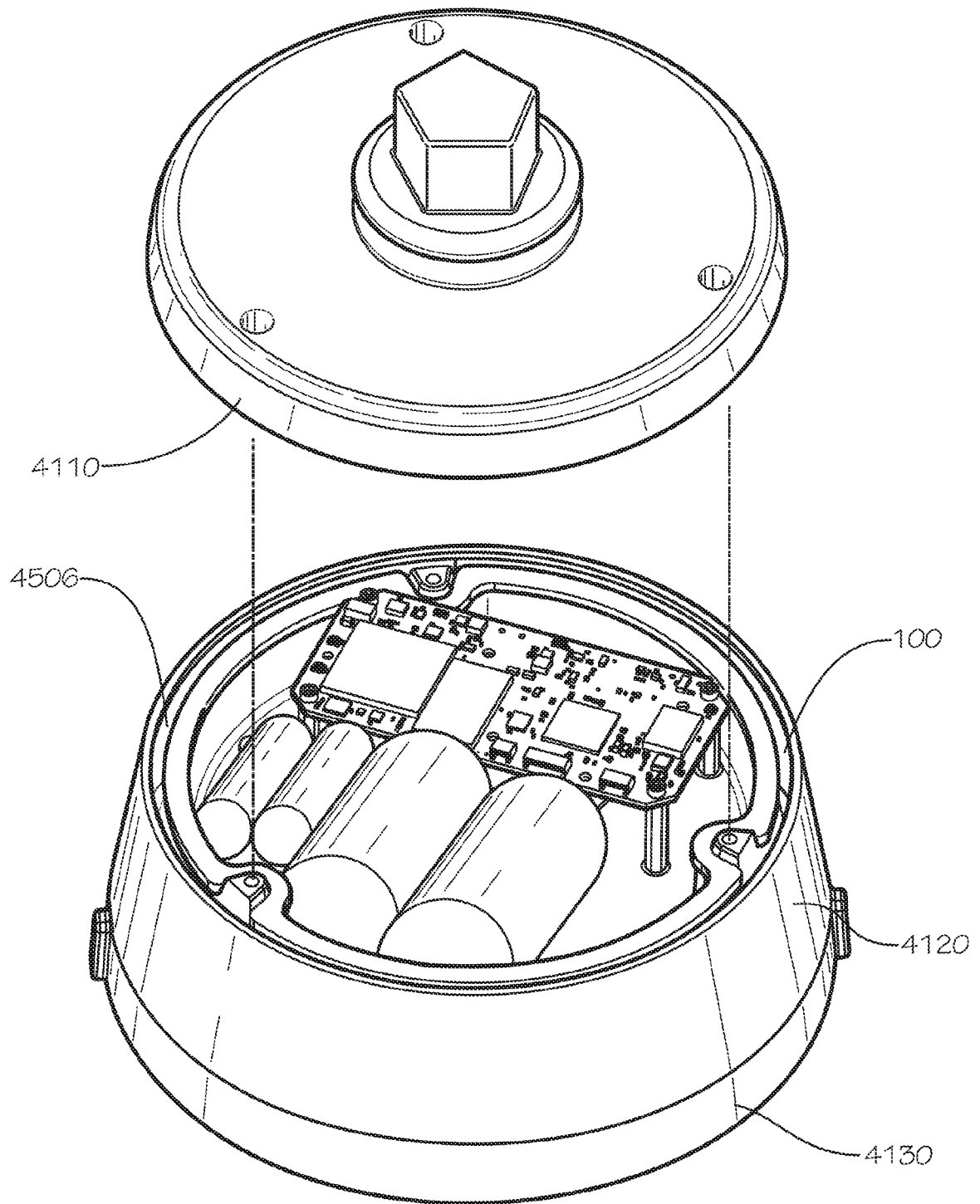


**FIG. 43**

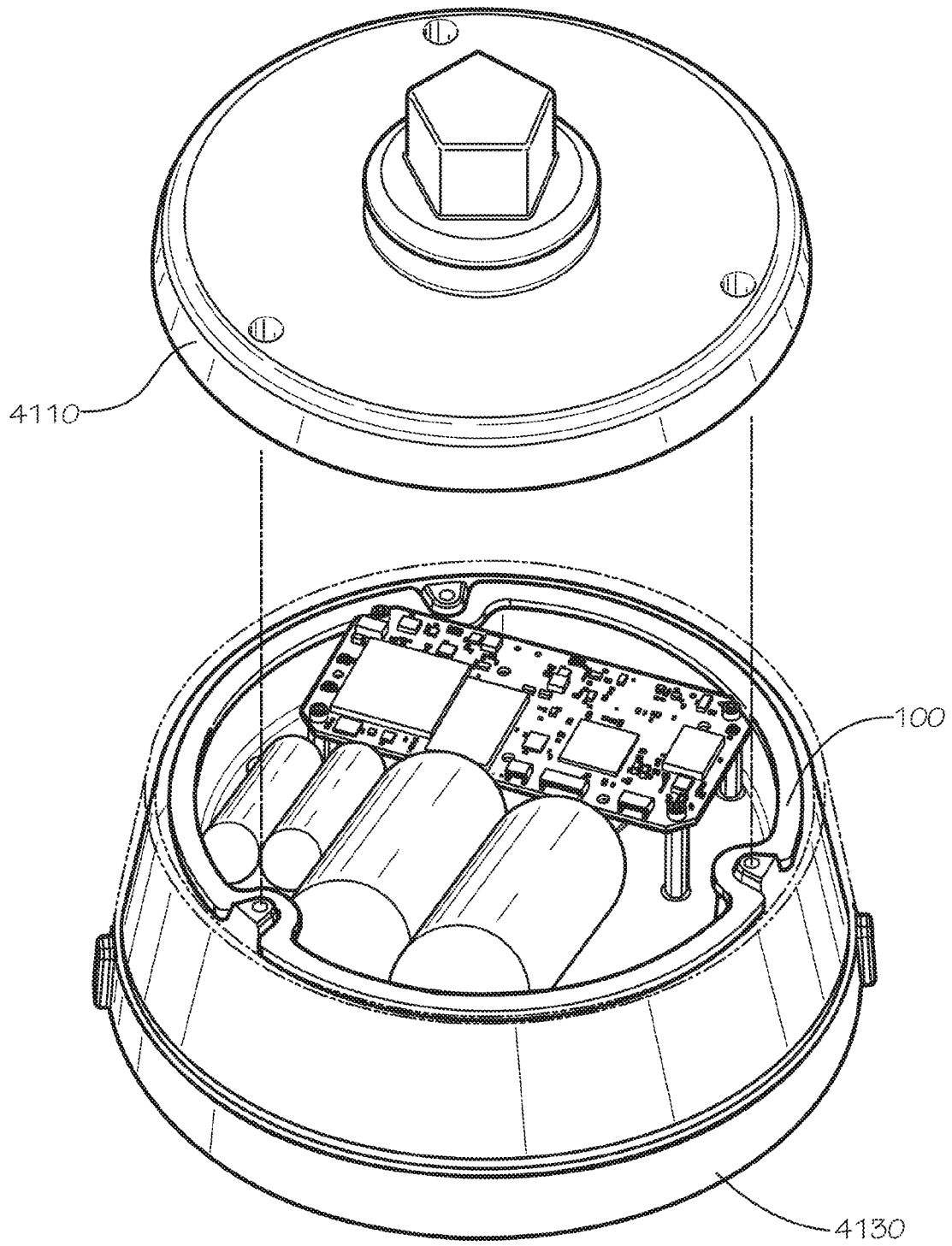




**FIG. 44**



**FIG. 45**



**FIG. 46**

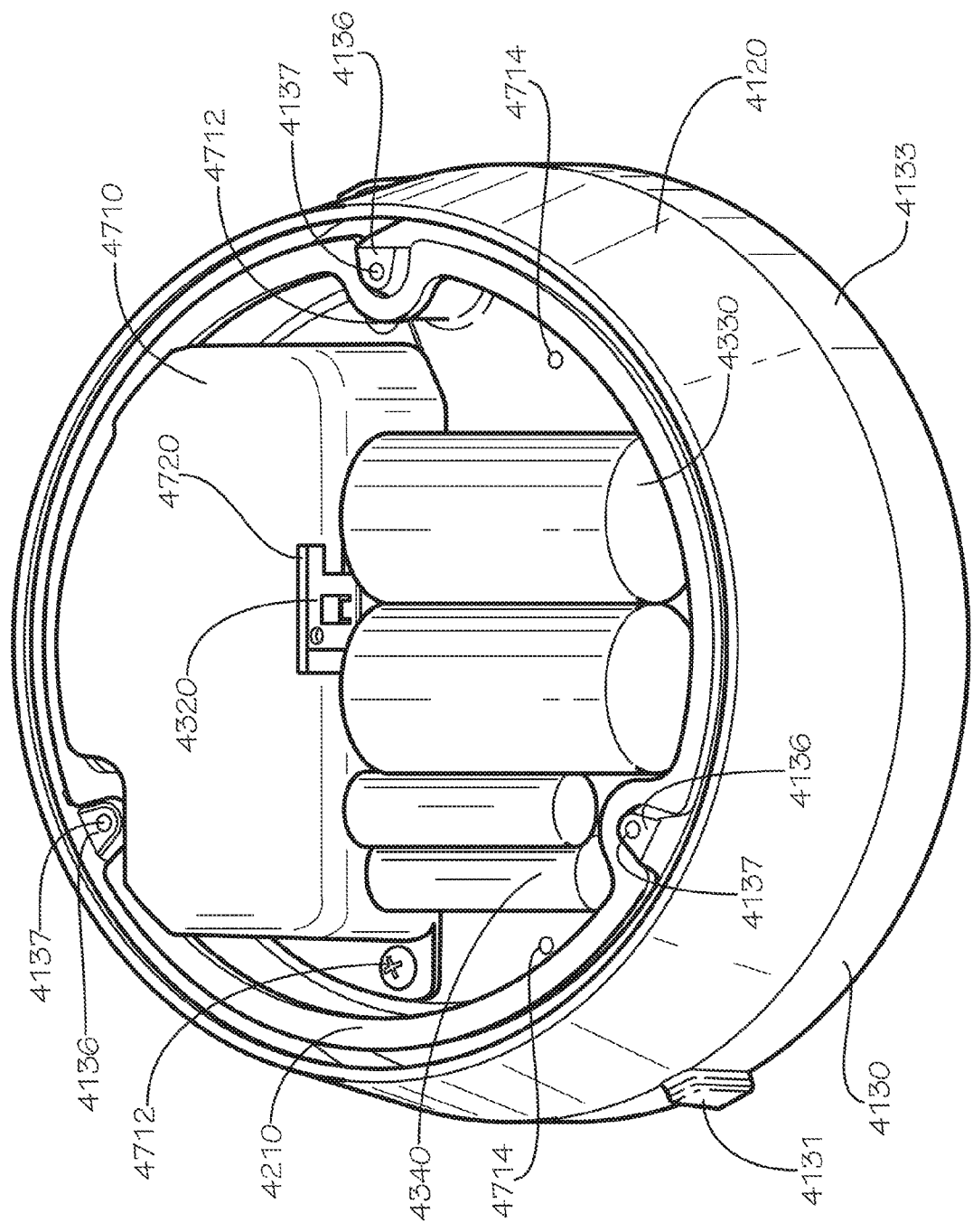


FIG. 47

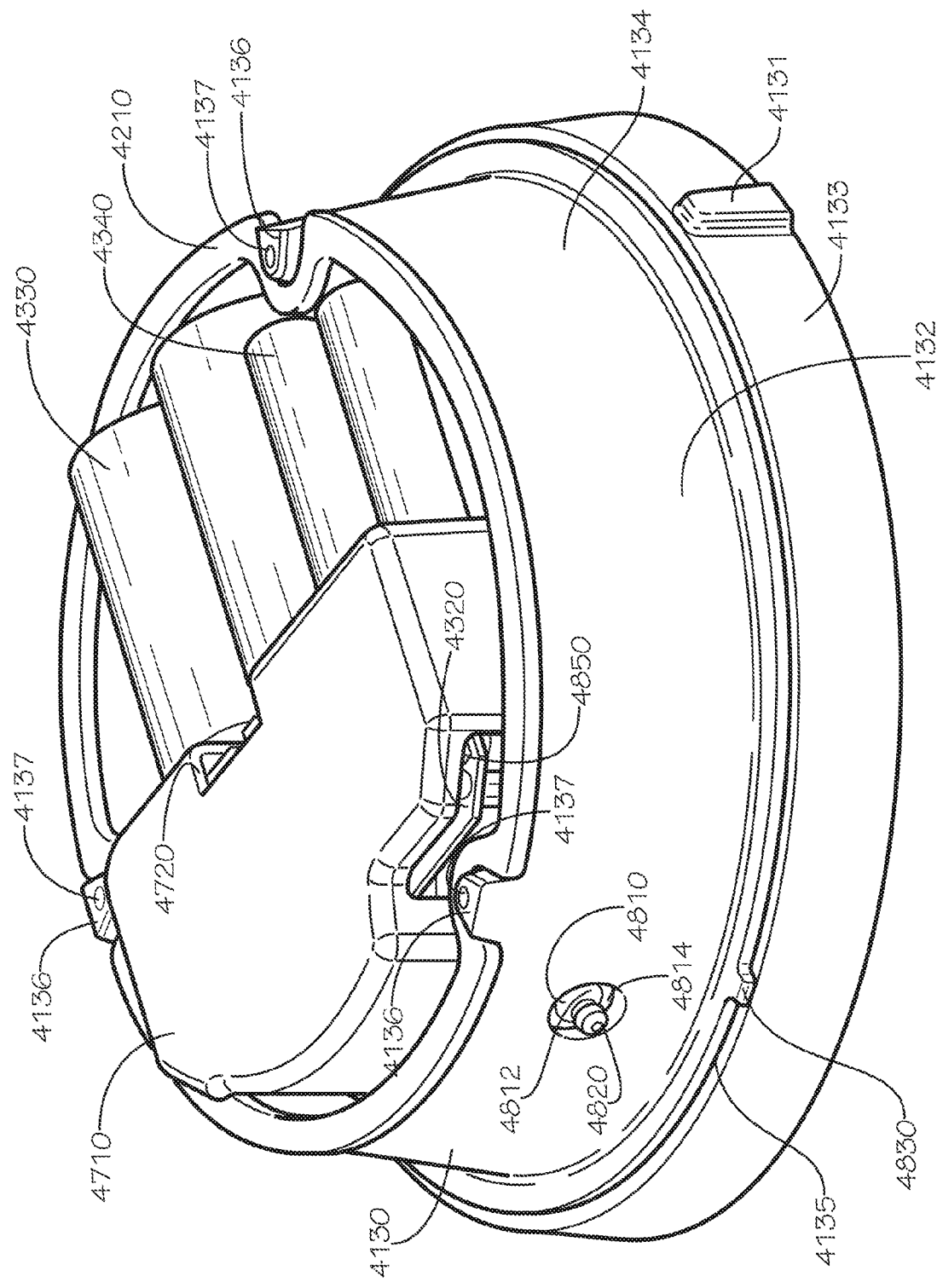
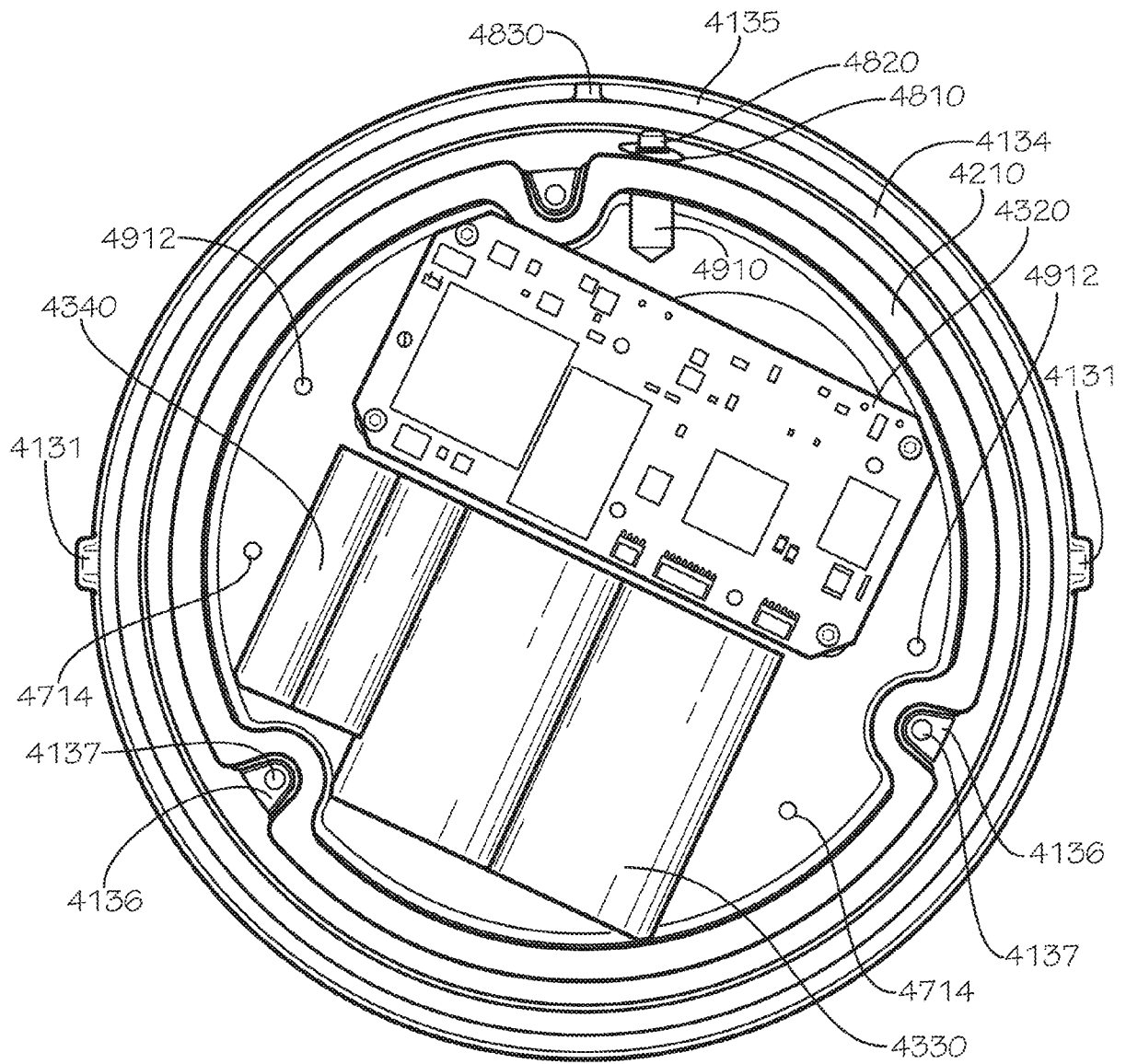
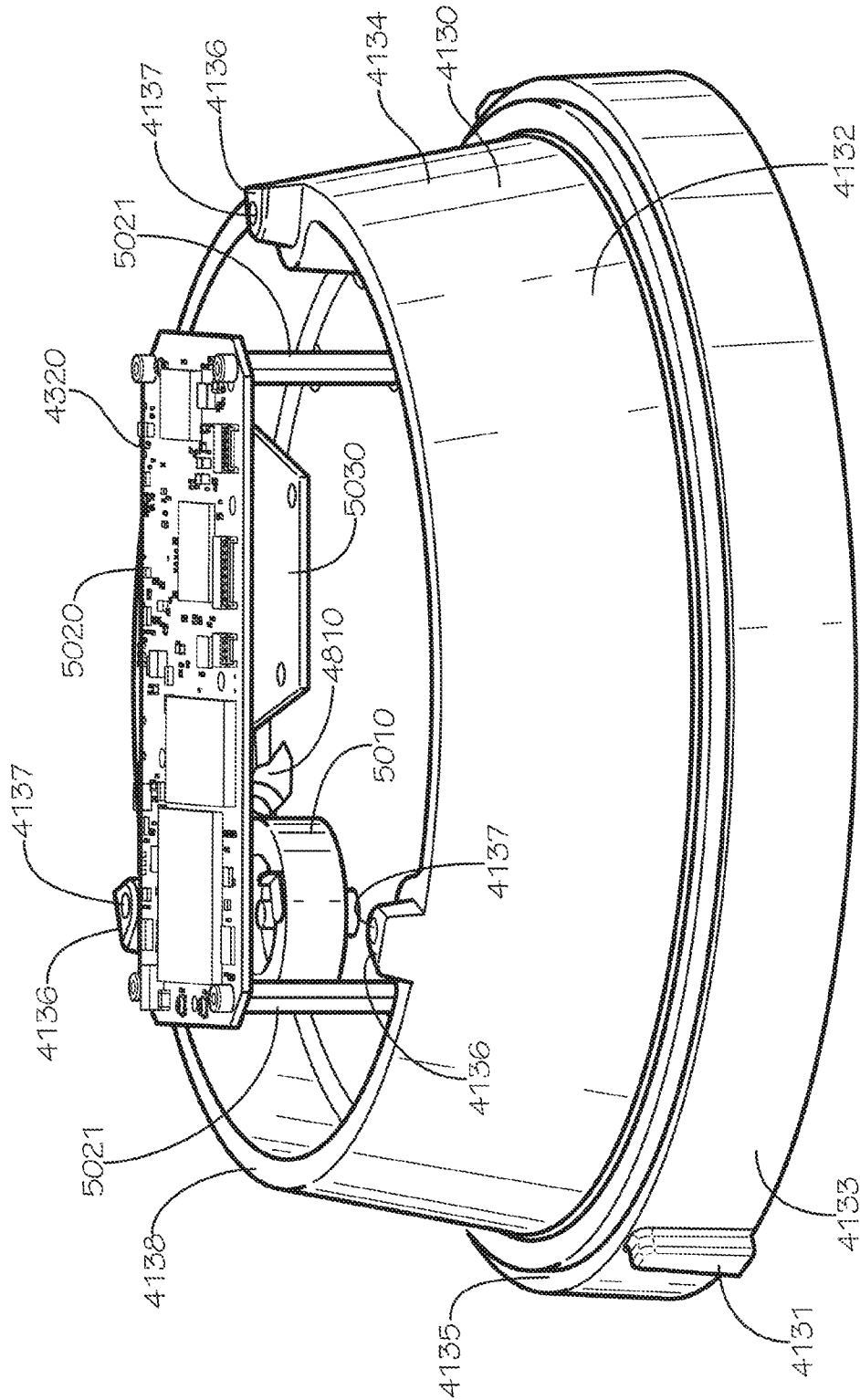


FIG. 48



**FIG. 49**



# FIG. 50

