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(54) **MAGNETICALLY MANEUVERABLE IN-VIVO DEVICE**

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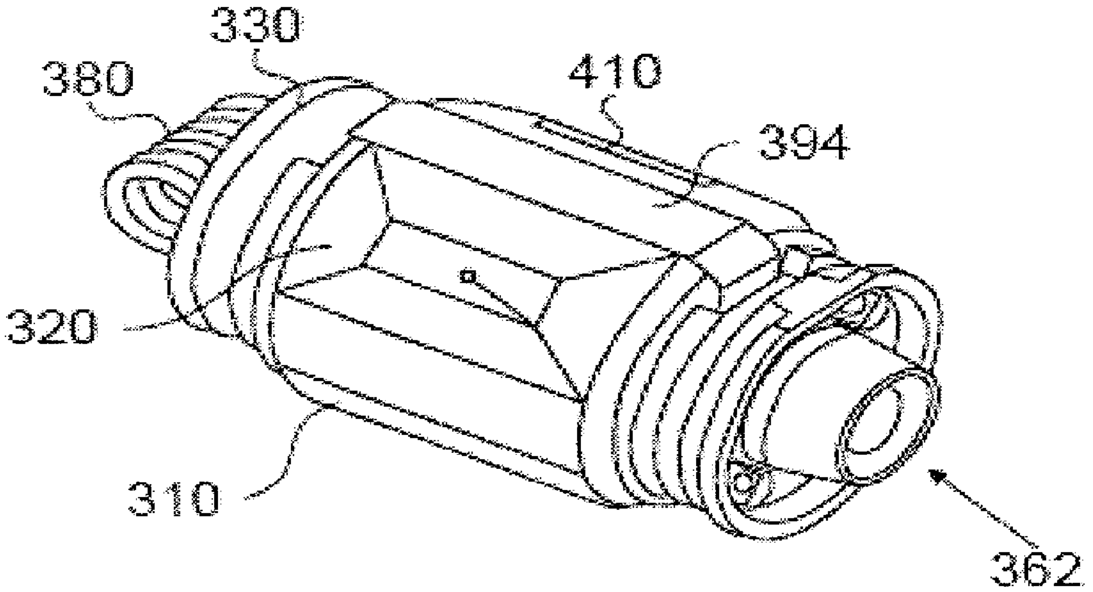
(57) **ABSTRACT**

An in-vivo device includes a magnetic steering unit (MSU) to maneuver it by an external electromagnetic field. The MSU may include a permanent magnets assembly to produce a magnetic force for navigating the device. The MSU may include a magnets carrying assembly (MCA) to accommodate the permanent magnet(s). The MCA may be designed to generate eddy currents, in response to AC magnetic field, to apply a repelling force. The in-vivo device may also include a multilayered imaging and sensing printed circuit board (MISP) to capture and transmit images. The MISP may include a sensing coil assembly (SCA) to sense electromagnetic fields to determine a location/orientation/angular position of the in-vivo device. Data representing location/orientation/angular position of the device may be used by a maneuvering system to generate a steering magnetic field to steer the in-vivo device from one location or state to another location or state.



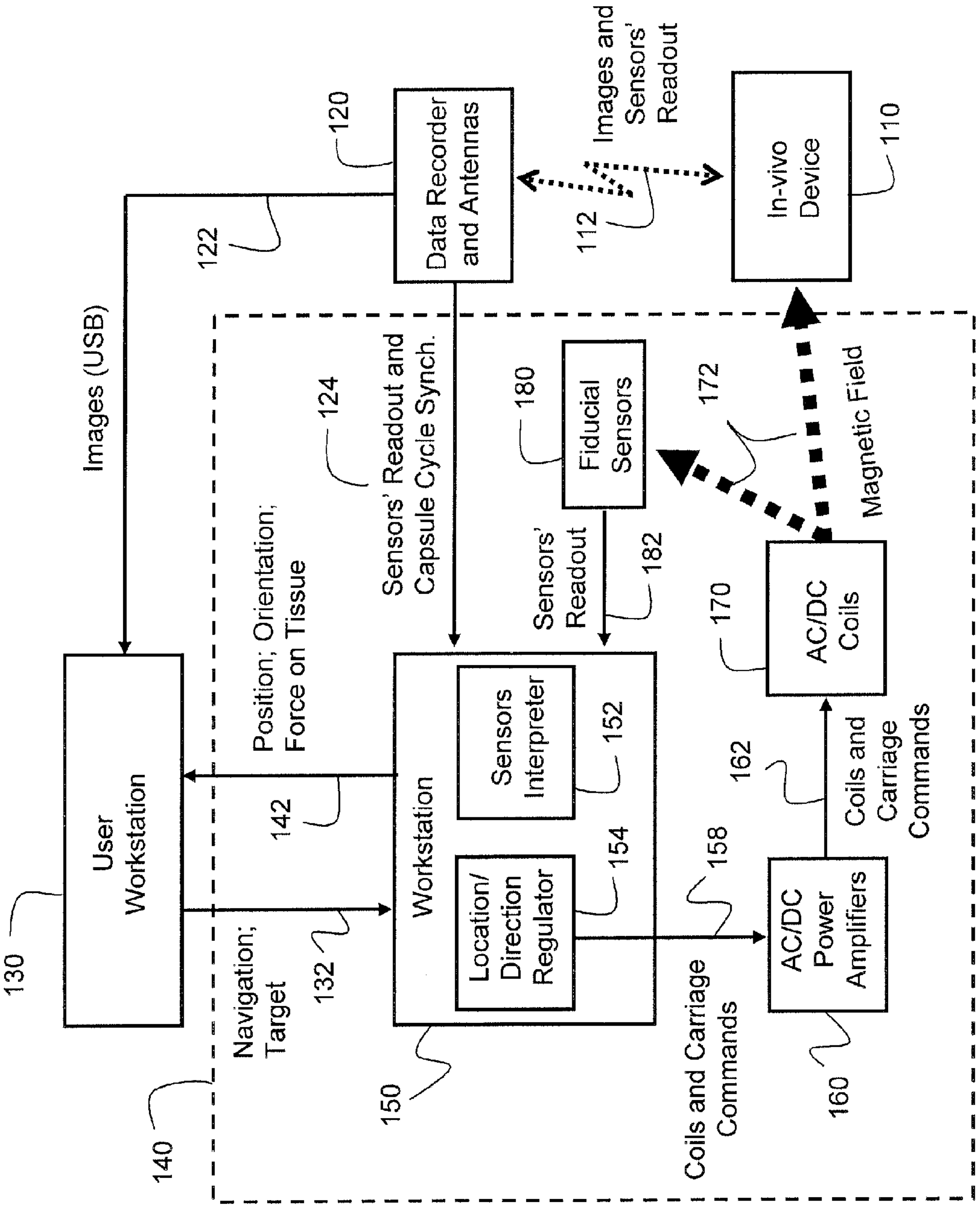

Images and Sensors' Readout
120
Data Recorder and Antennas
112
In-vivo Device
110
122
Images (USB)
124
Sensors' Readout and Capsule Cycle Synch.
180
Fiducial Sensors
172
Magnetic Field
182
Sensors' Readout
170
AC/DC Coils
User Workstation
130
Position; Orientation; Force on Tissue
142
Workstation
Sensors Interpreter
152
Location/ Direction Regulator
154
158
162
Coils and Carriage Commands
AC/DC Power Amplifiers
160
Navigation; Target
132
150
140
Coils and Carriage Commands

Fig. 1

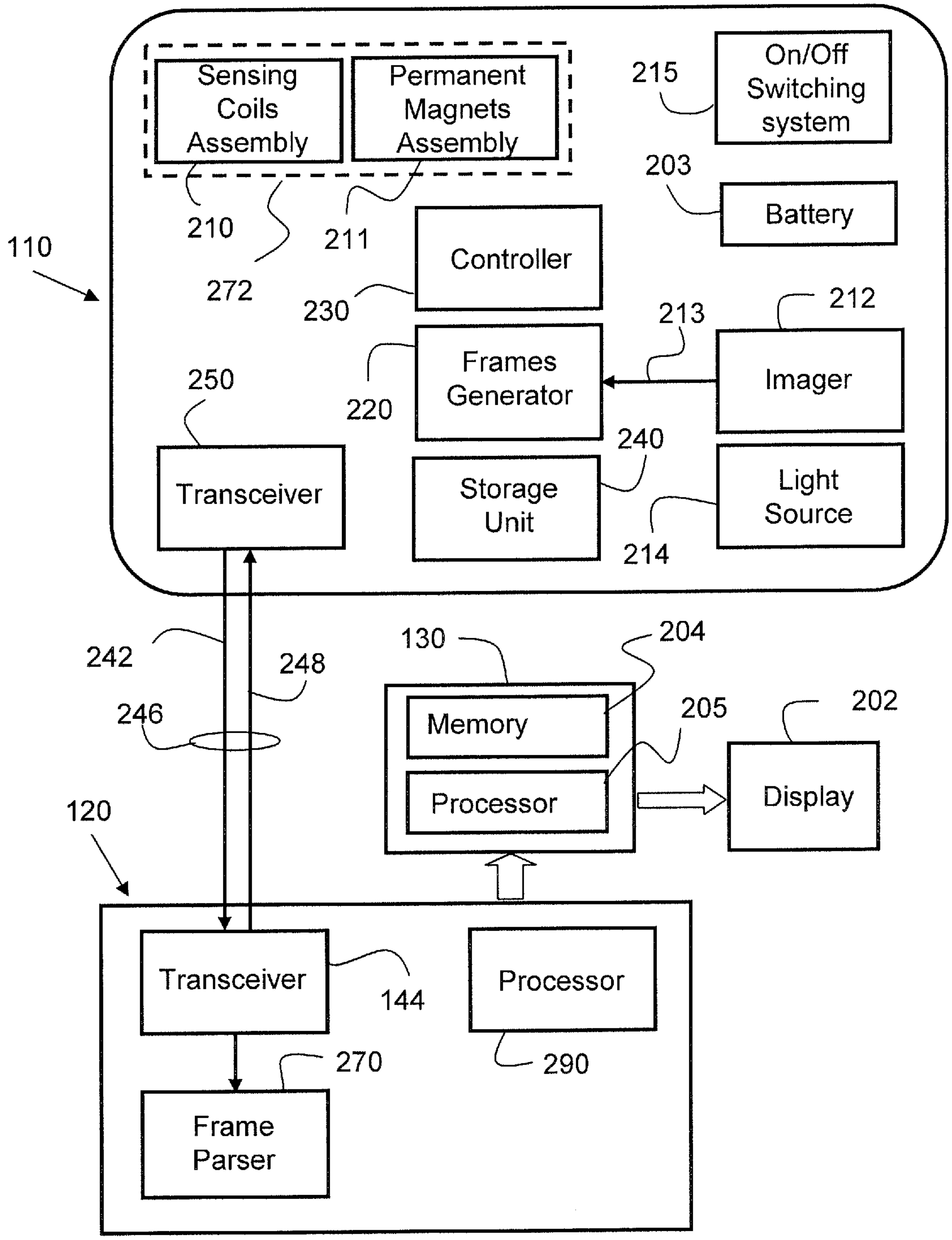

Sensing Coils Assembly
Permanent Magnets Assembly
215
On/Off Switching system
203
Battery
210
272
211
Controller
110
230
213
212
Imager
Frames Generator
220
250
Transceiver
240
Storage Unit
Light Source
214
242
248
246
130
204
Memory
205
Processor
202
Display
120
Transceiver
144
Processor
290
270
Frame Parser

Fig. 2

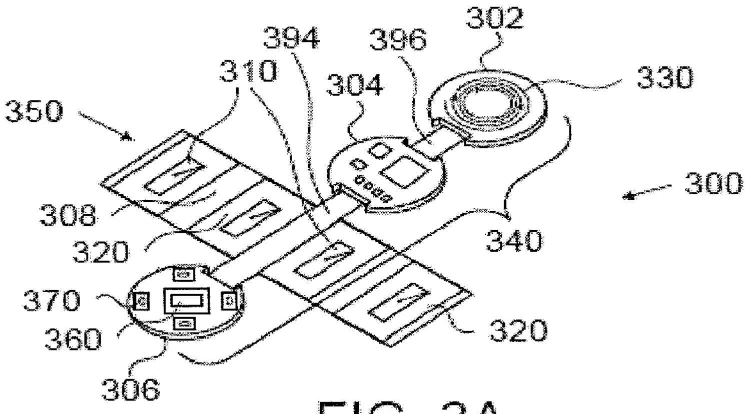


FIG. 3A

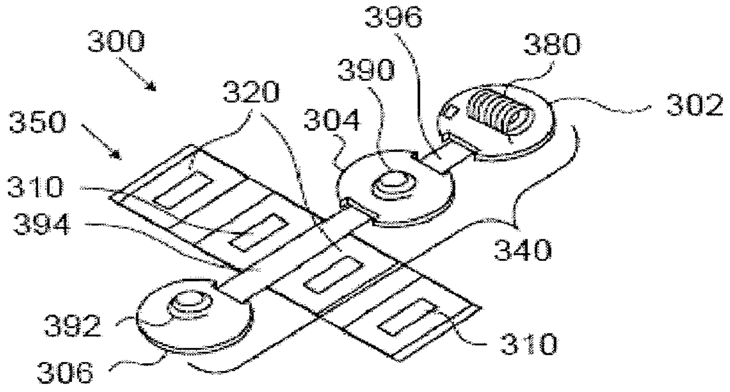


FIG. 3B

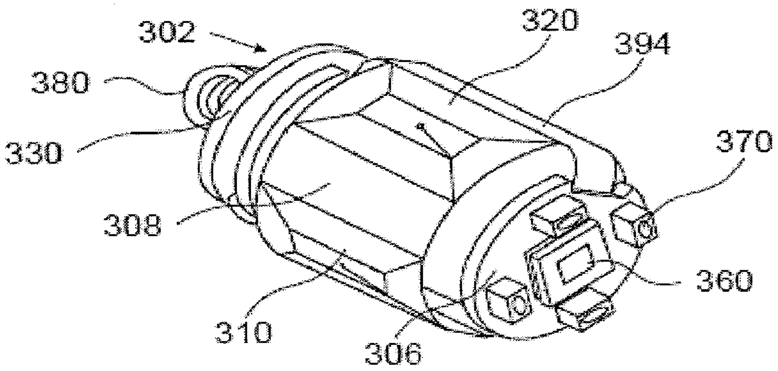


FIG. 3C

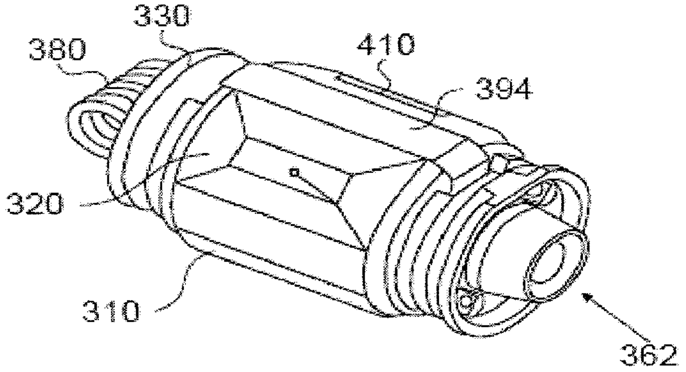


FIG. 3D

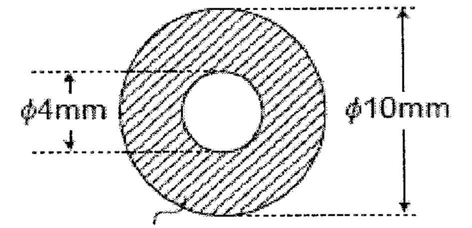


FIG. 4A

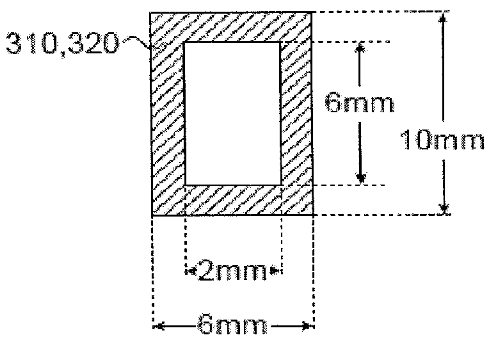


FIG. 4B

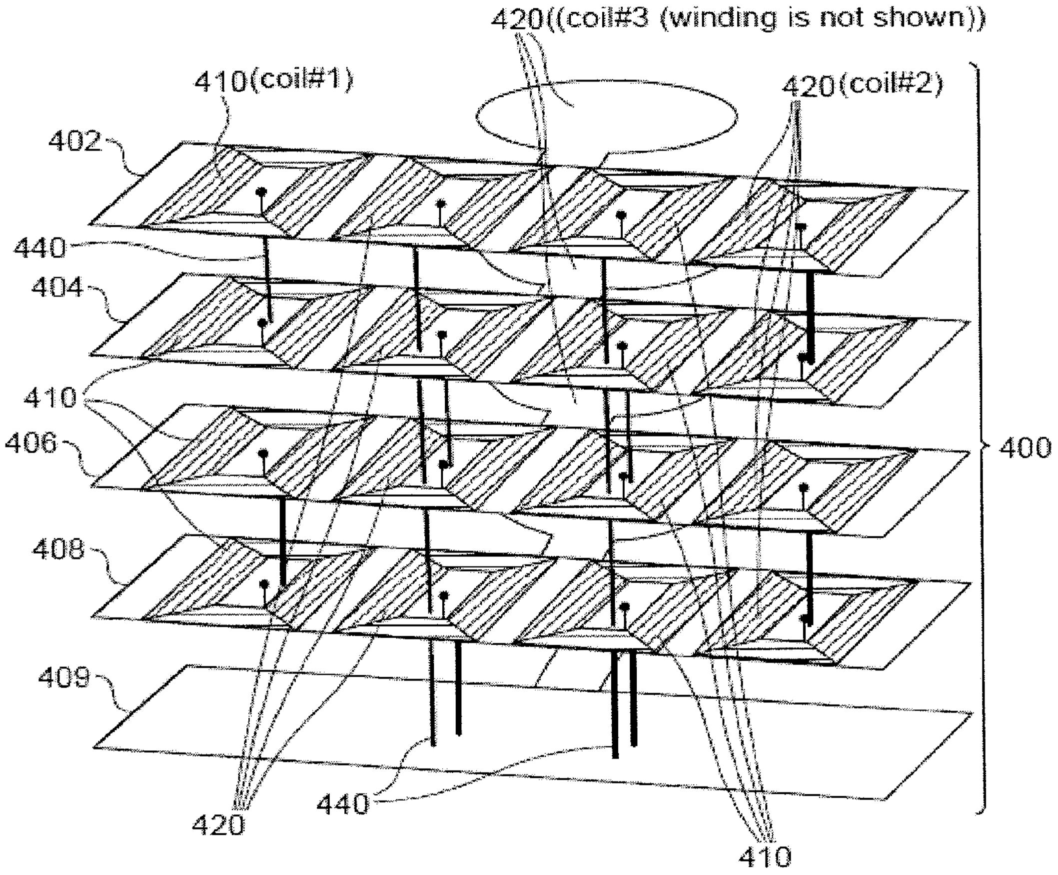


FIG. 5

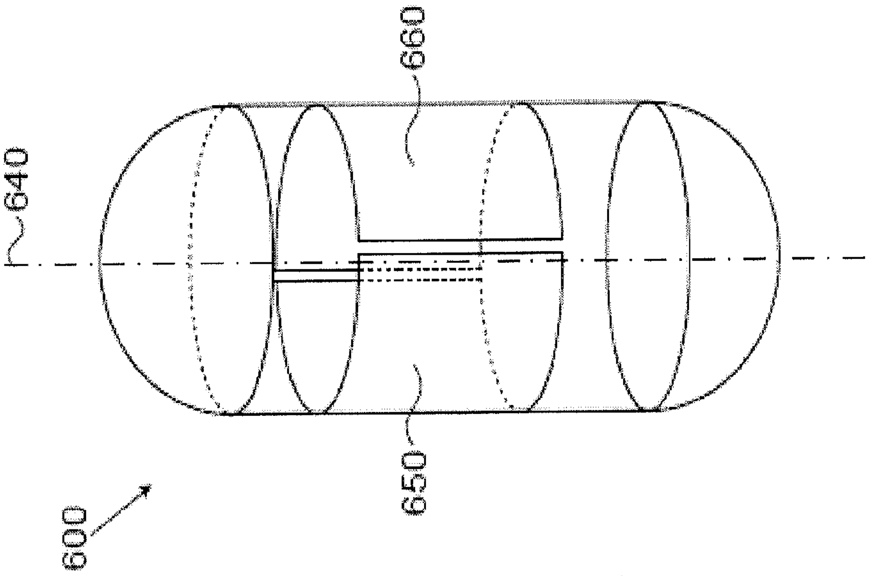


FIG. 6B

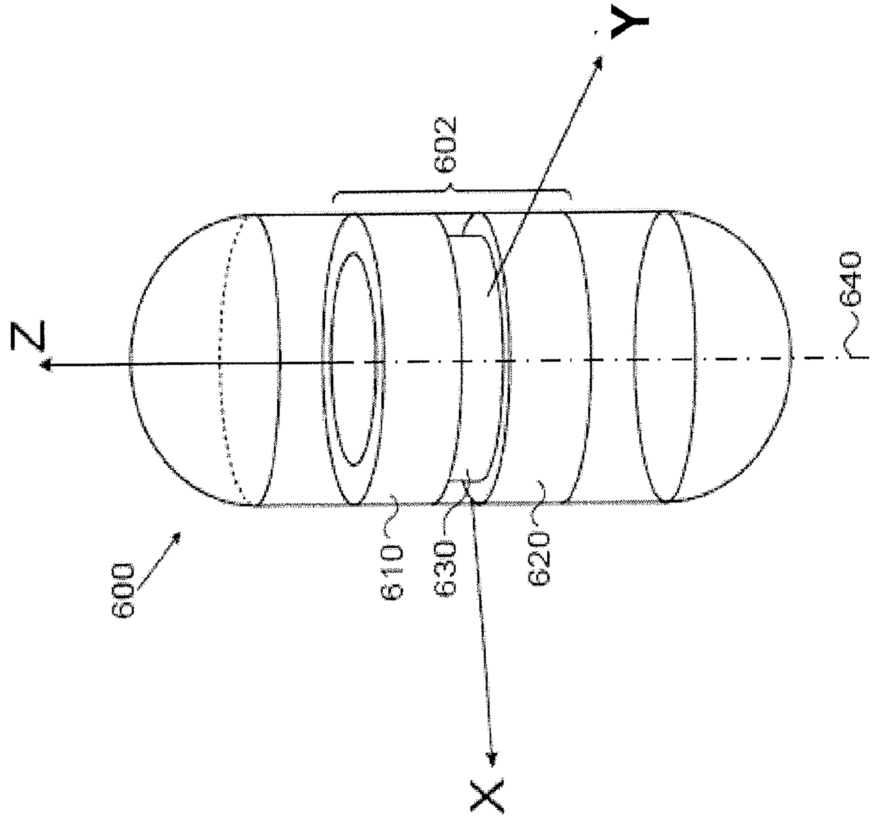


FIG. 6A

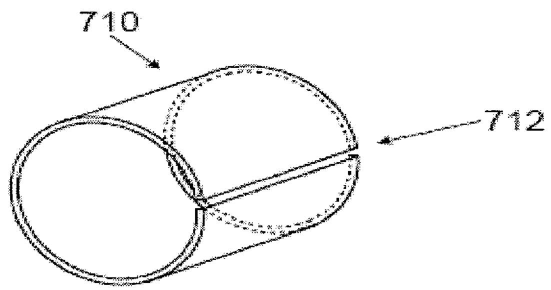


FIG. 7A

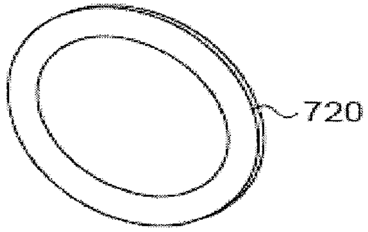


FIG. 7B

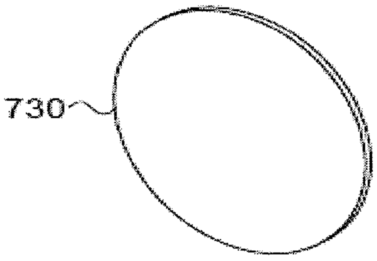


FIG. 7C

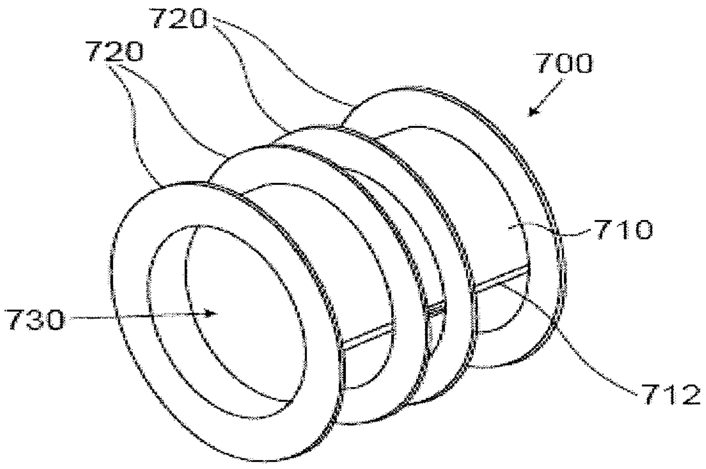


FIG. 7D

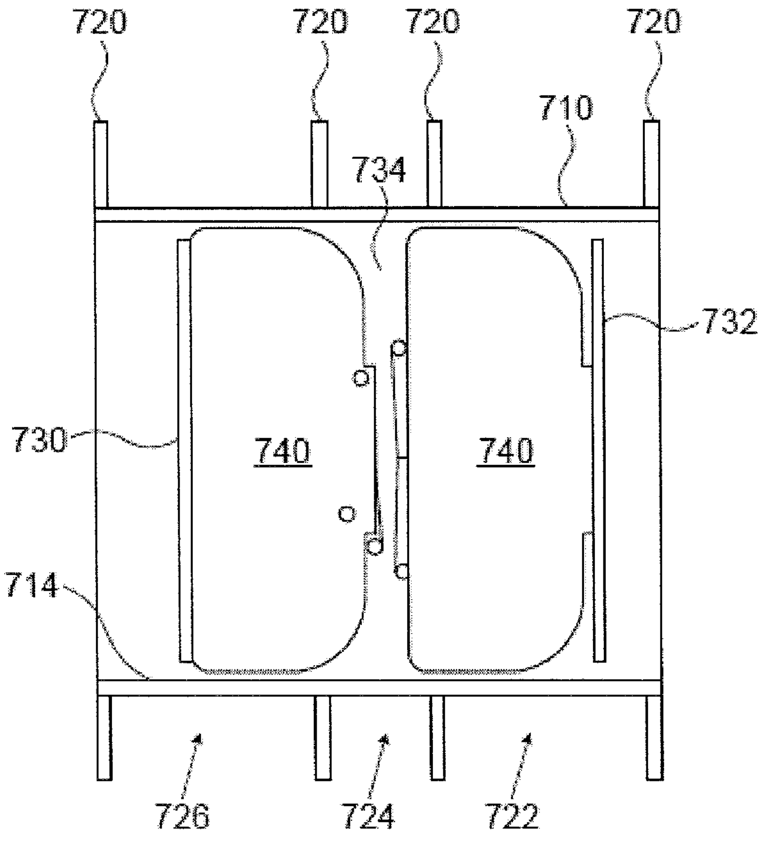

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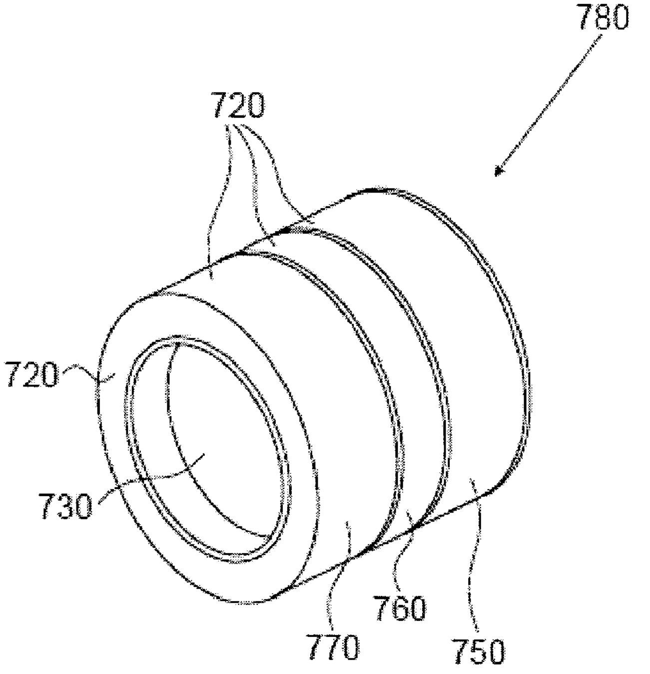
FIG. 7E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750

FIG. 7F

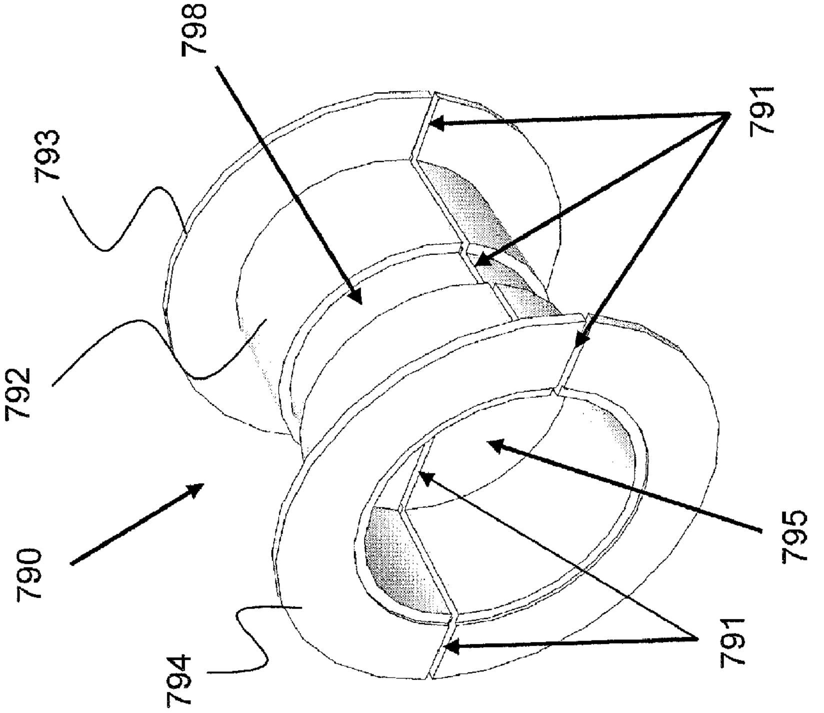

Fig. 7G

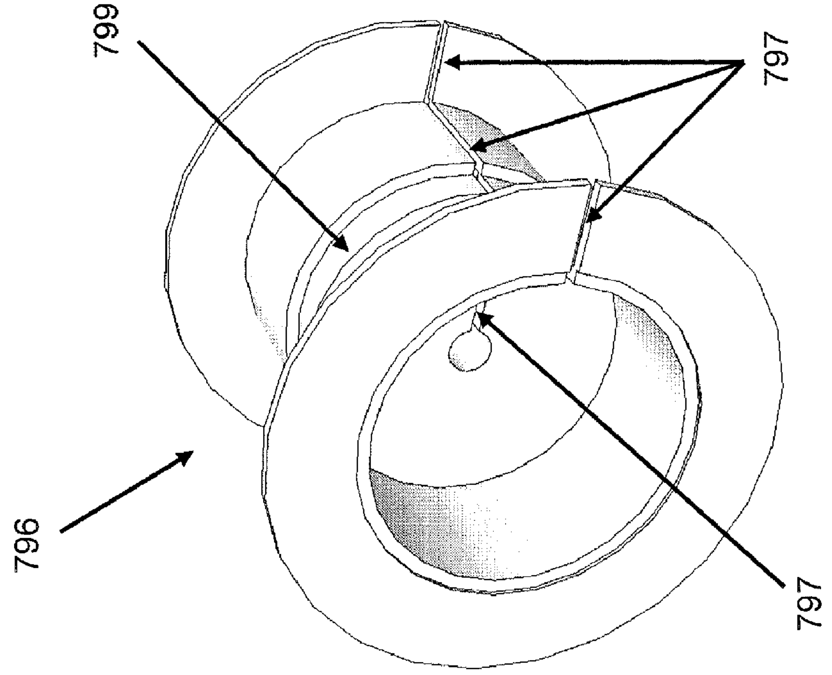

Fig. 7H

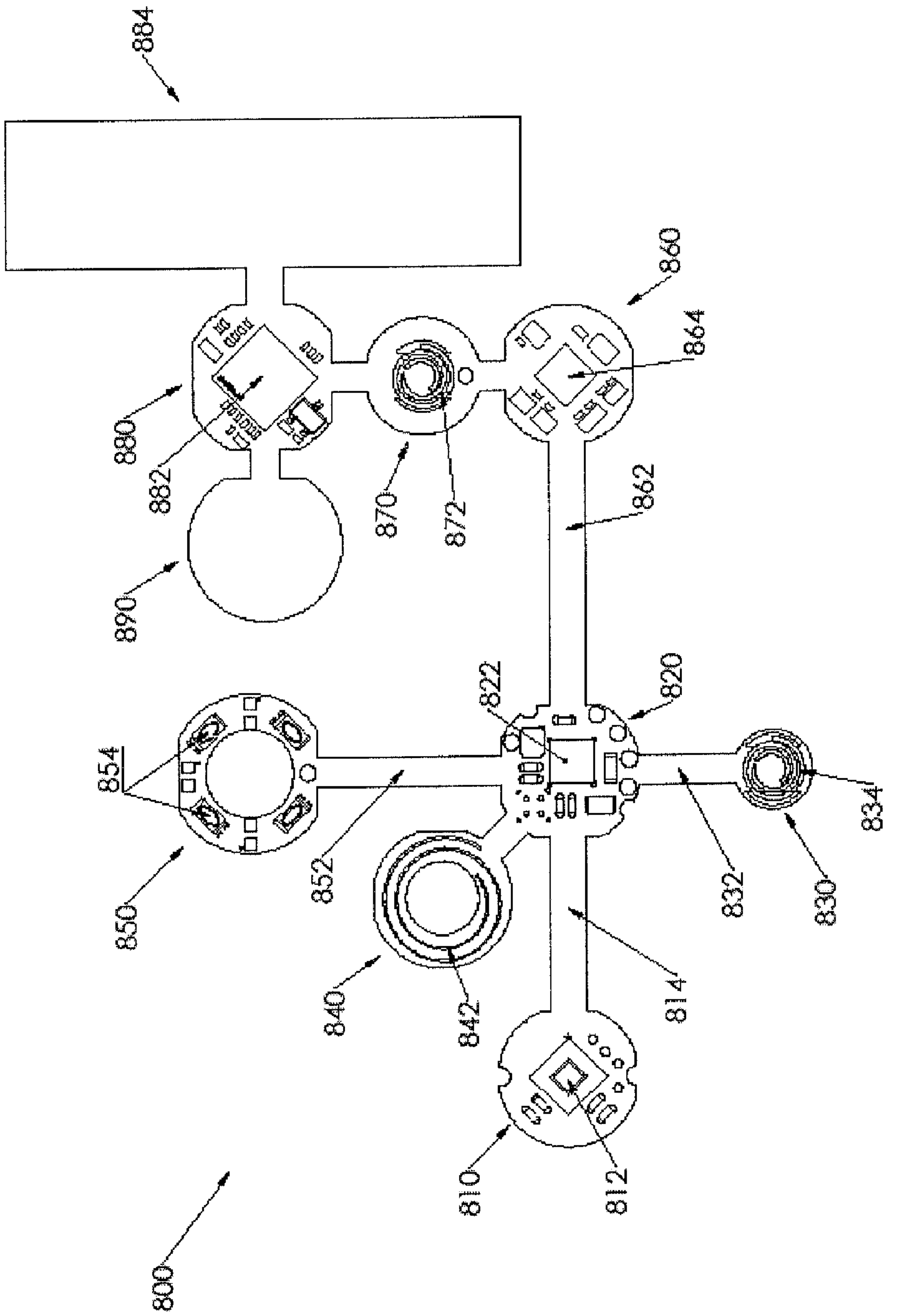
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Fig. 8

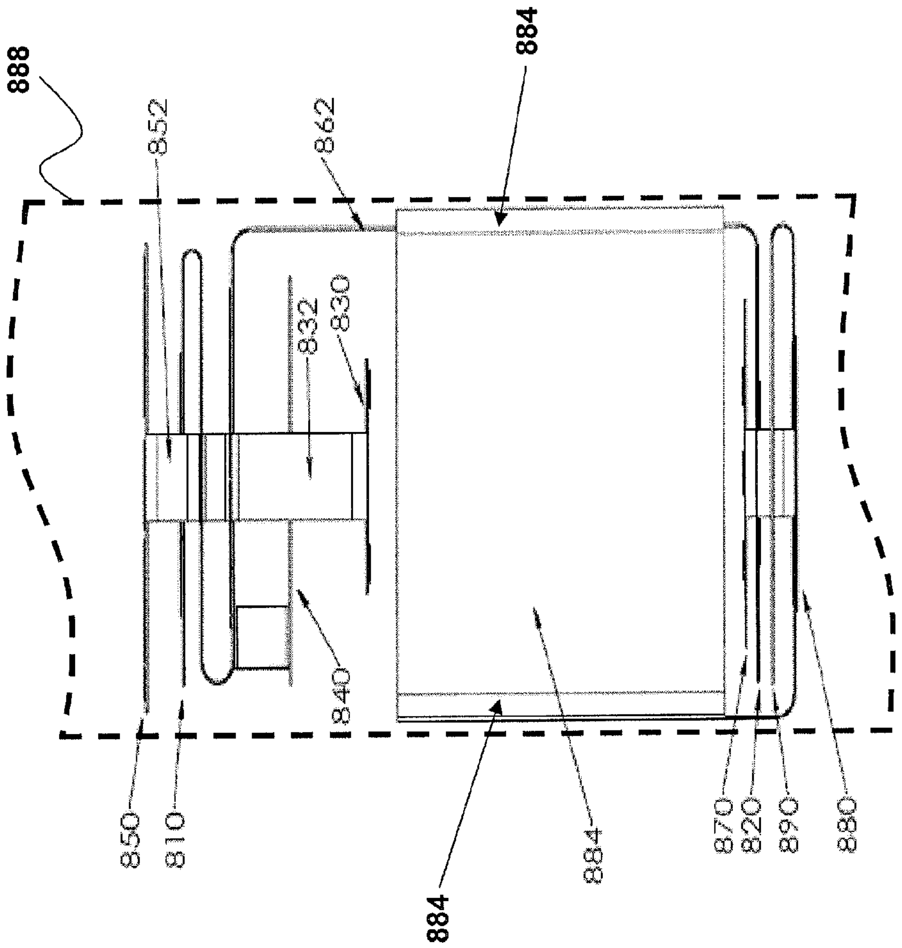

Fig. 9A

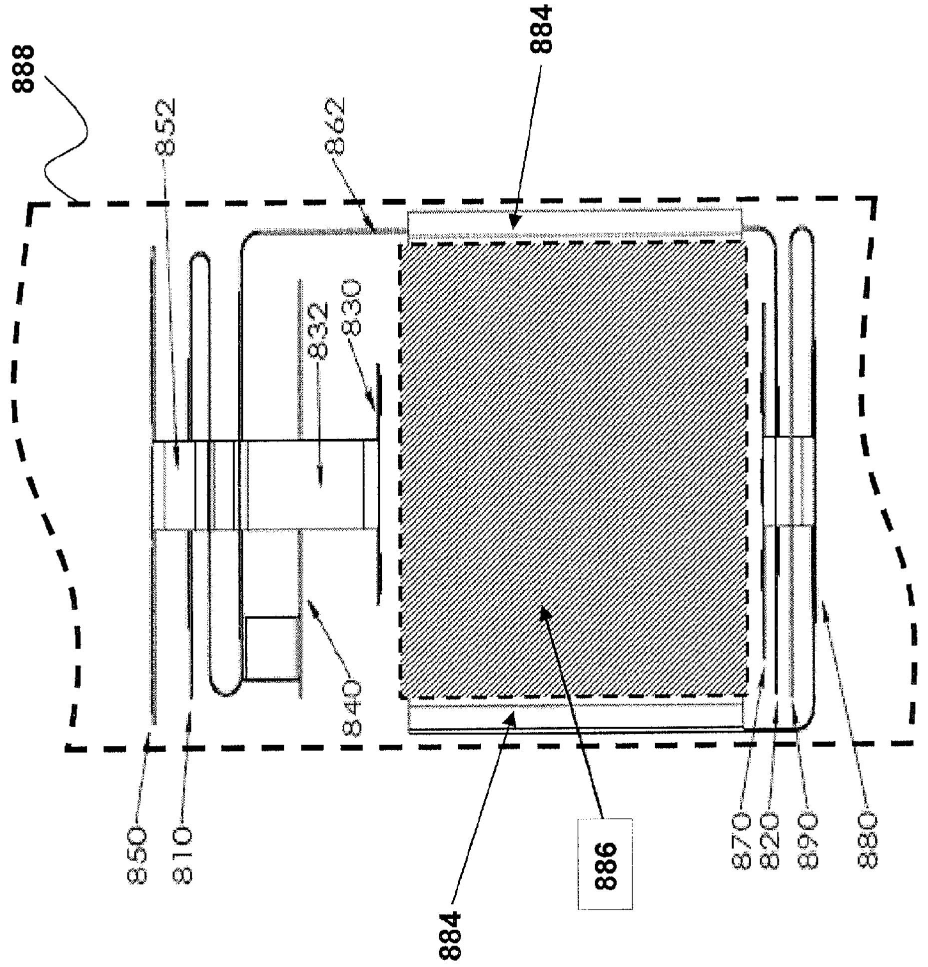

Fig. 9B

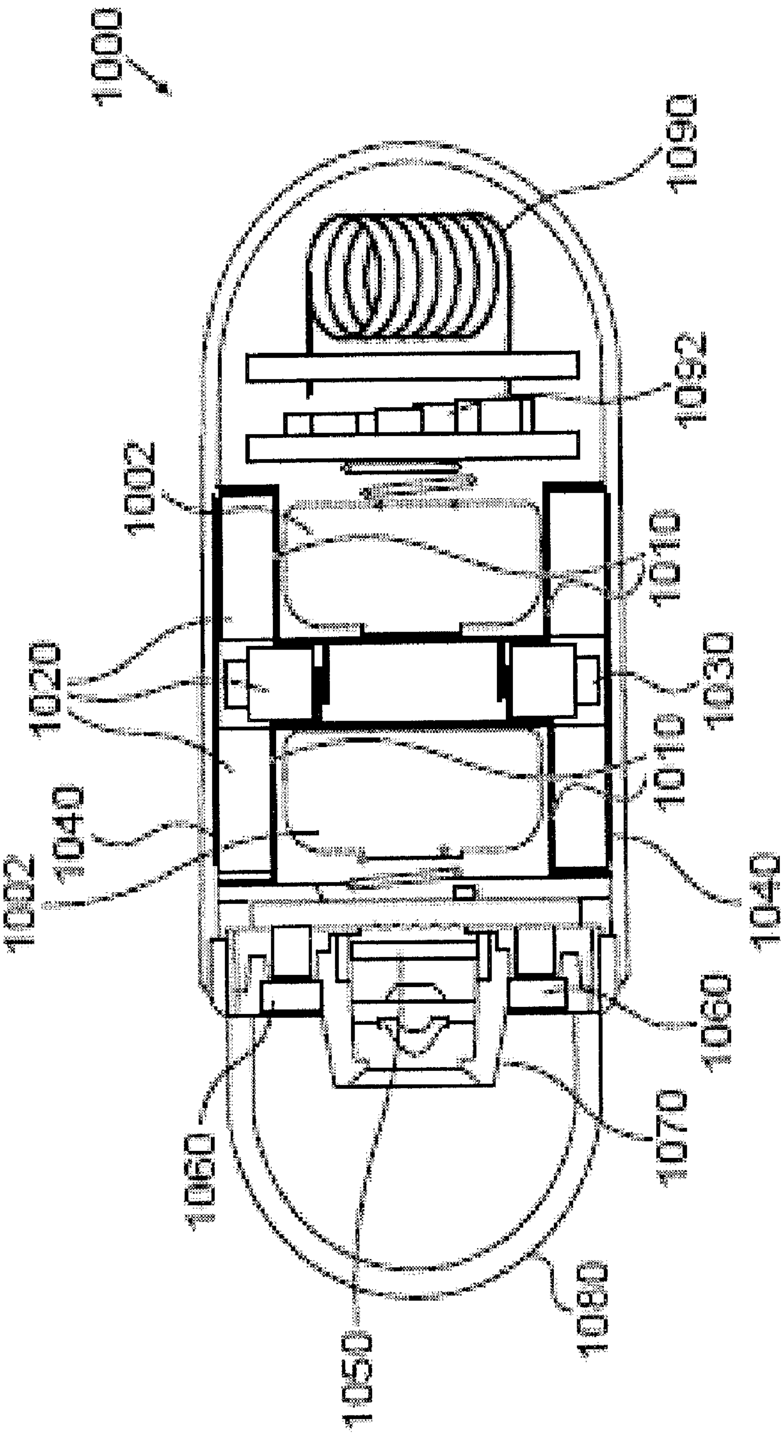
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FIG. 10A

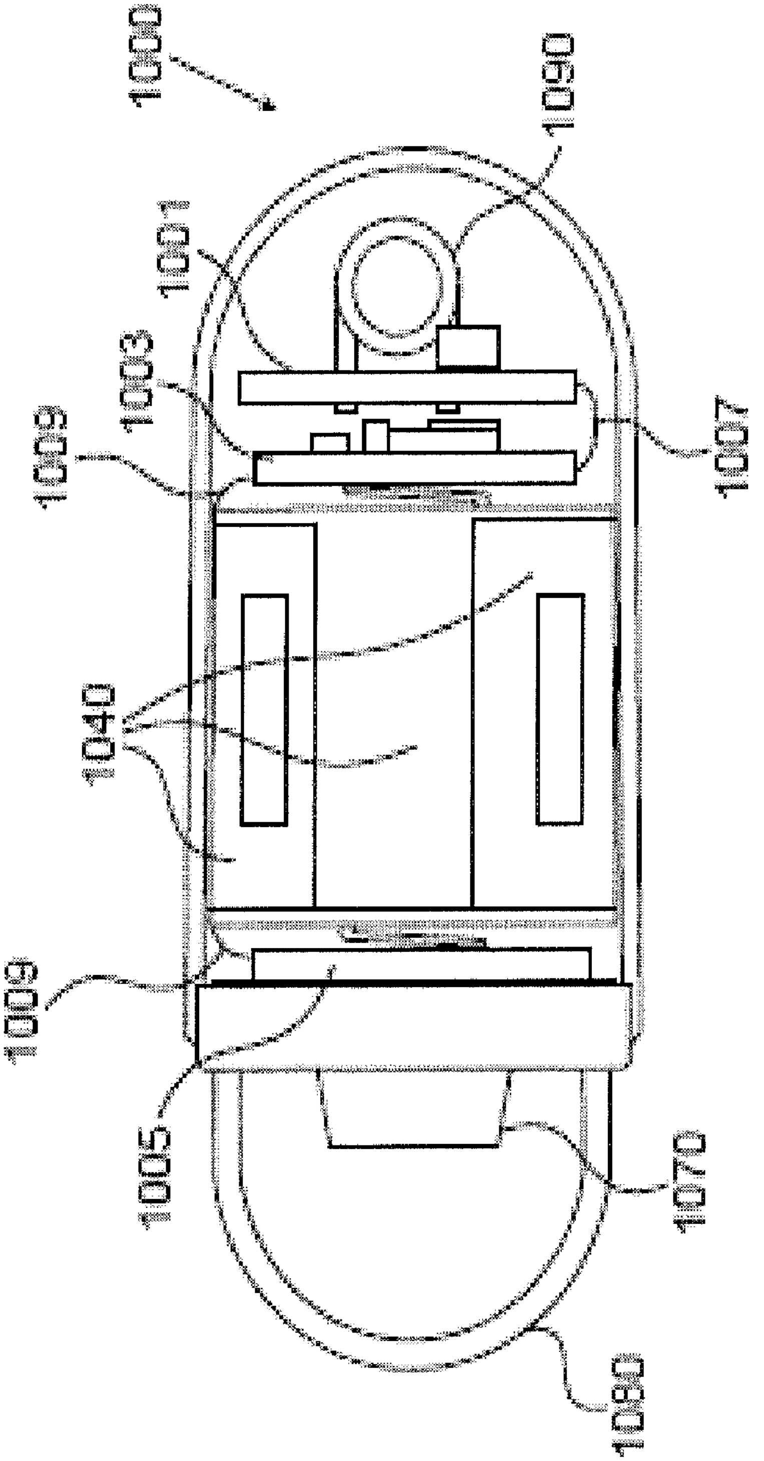
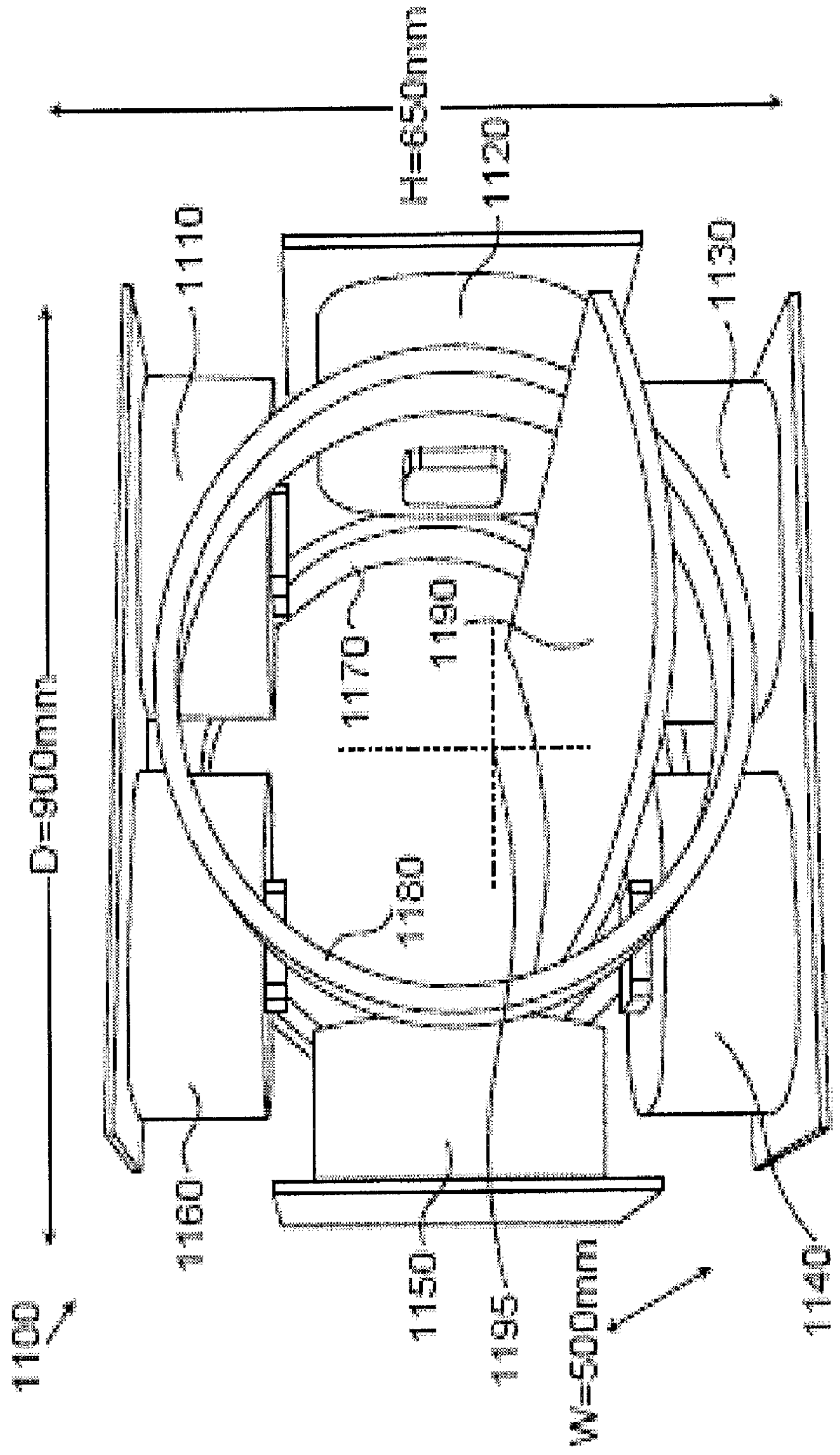


FIG. 10B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H=650mm
D=900mm
W=500mm

FIG. 11

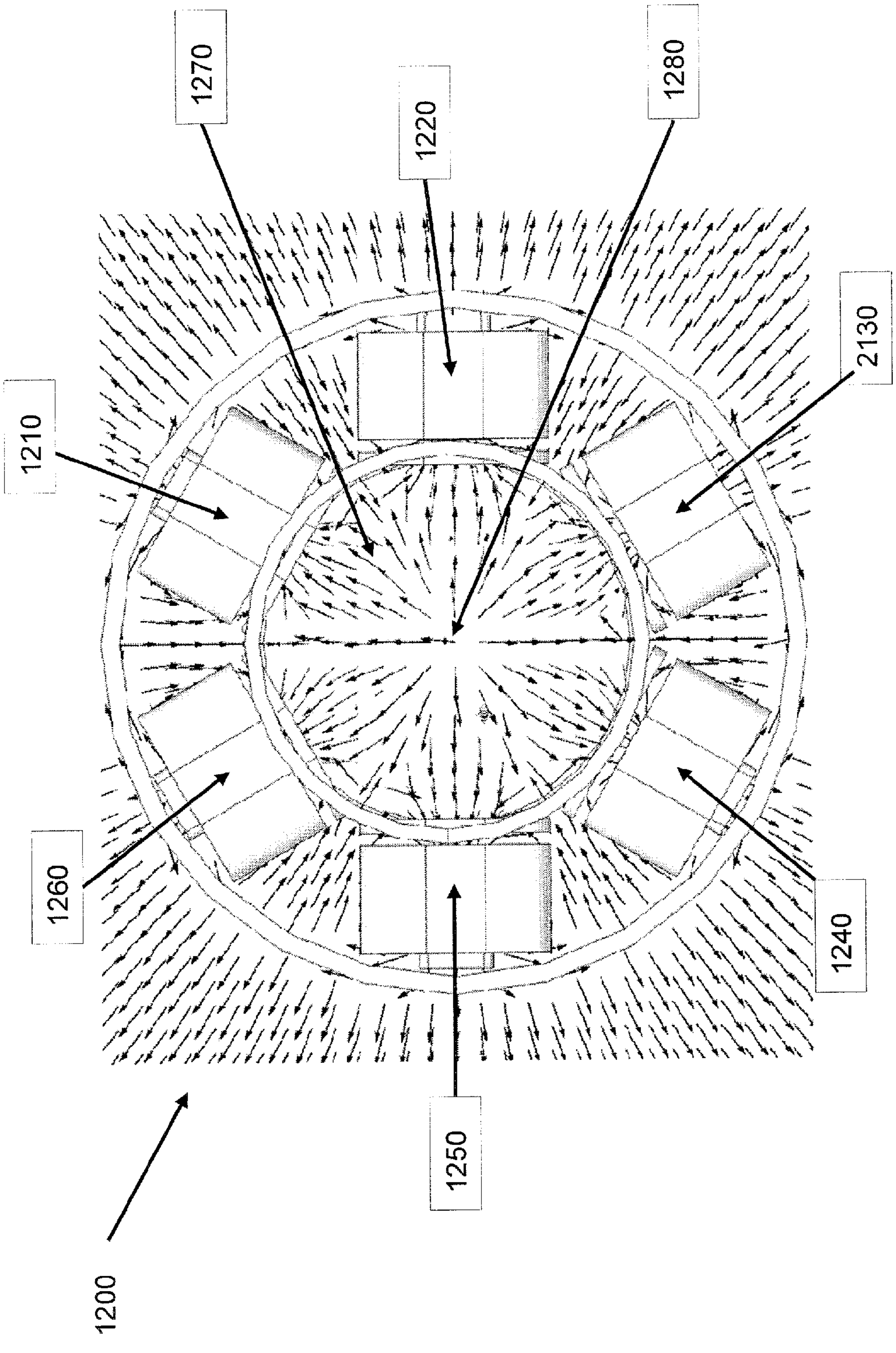

Fig. 12

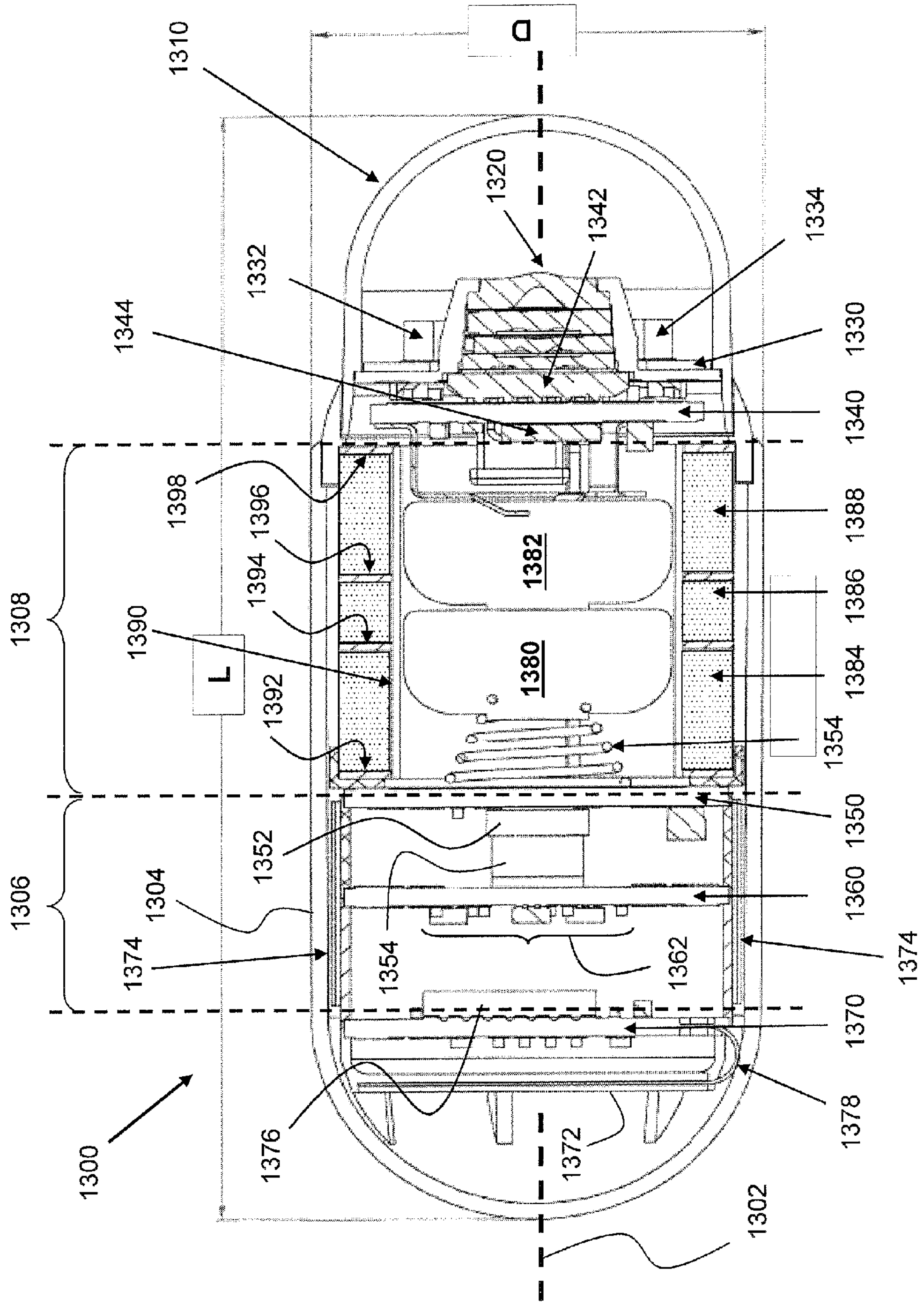
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Fig. 13A

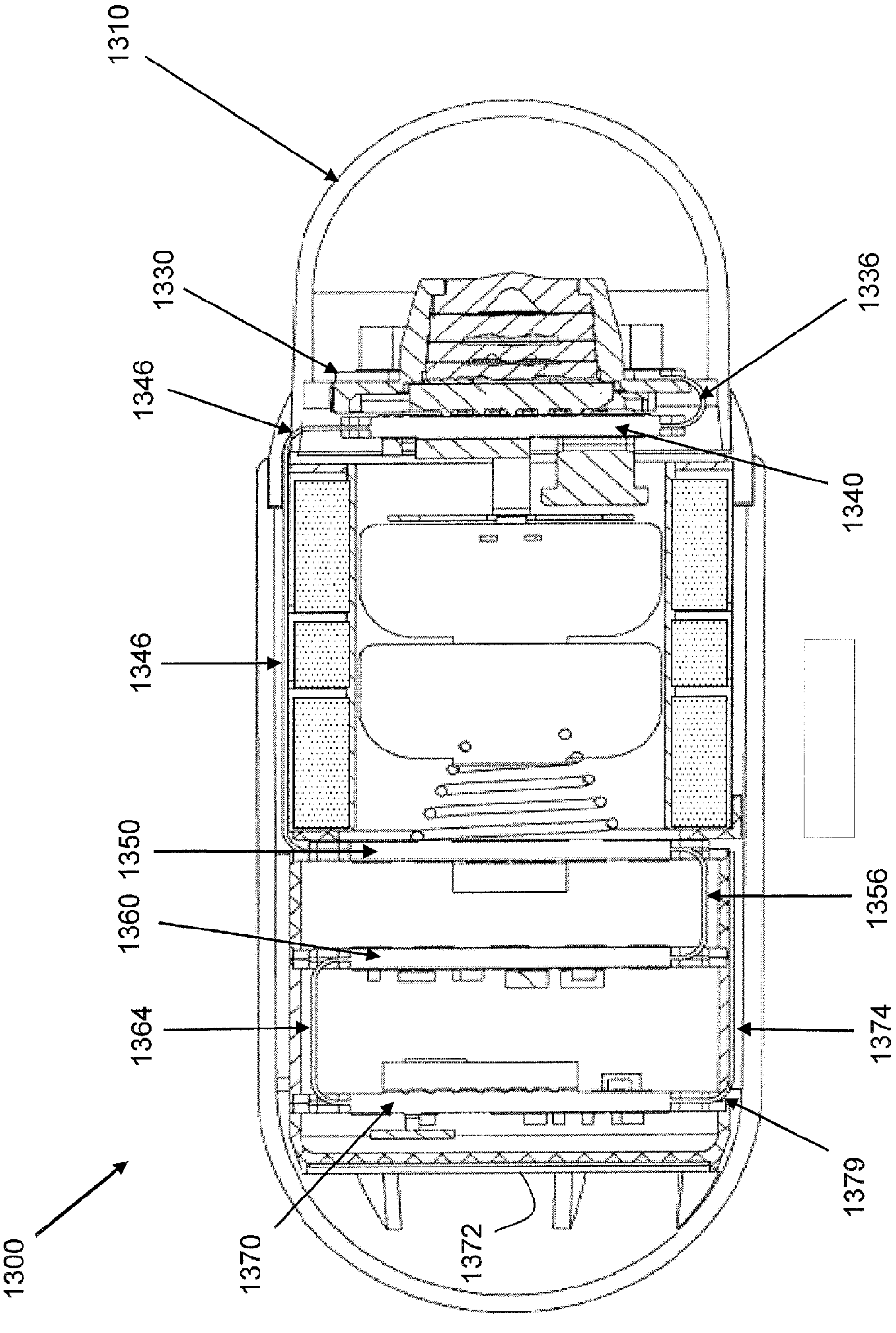
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Fig. 13B

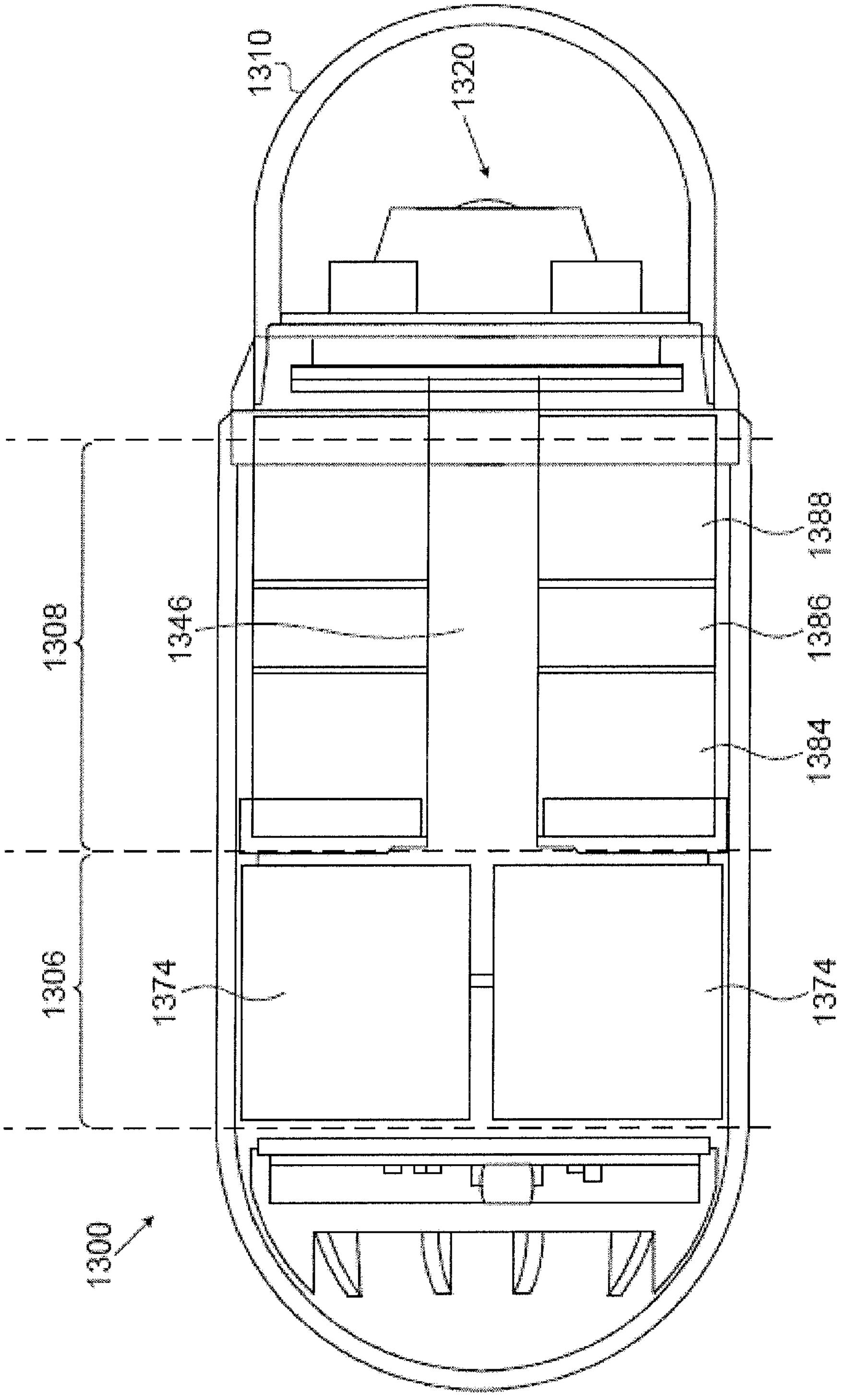

FIG. 14

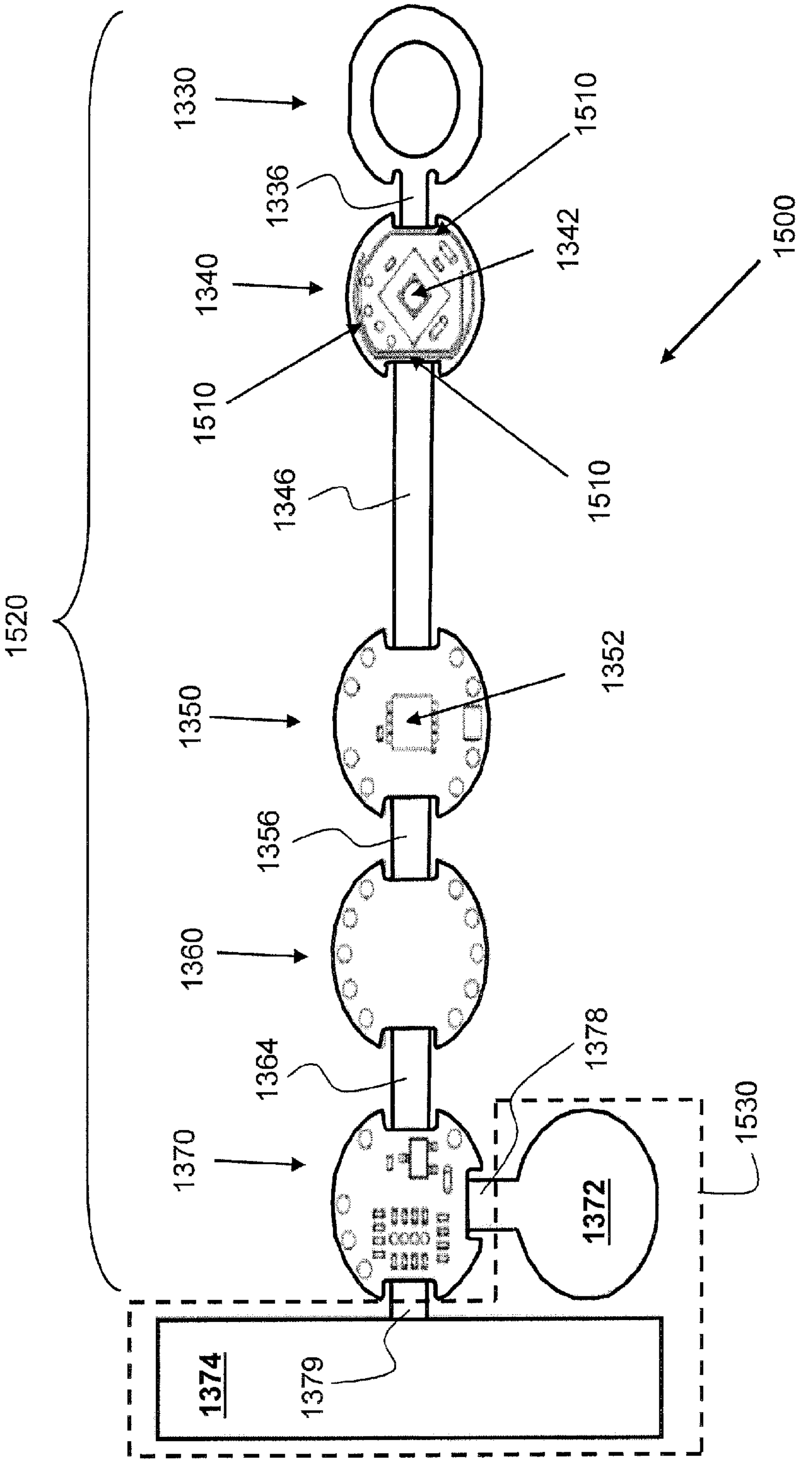
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Fig. 15A

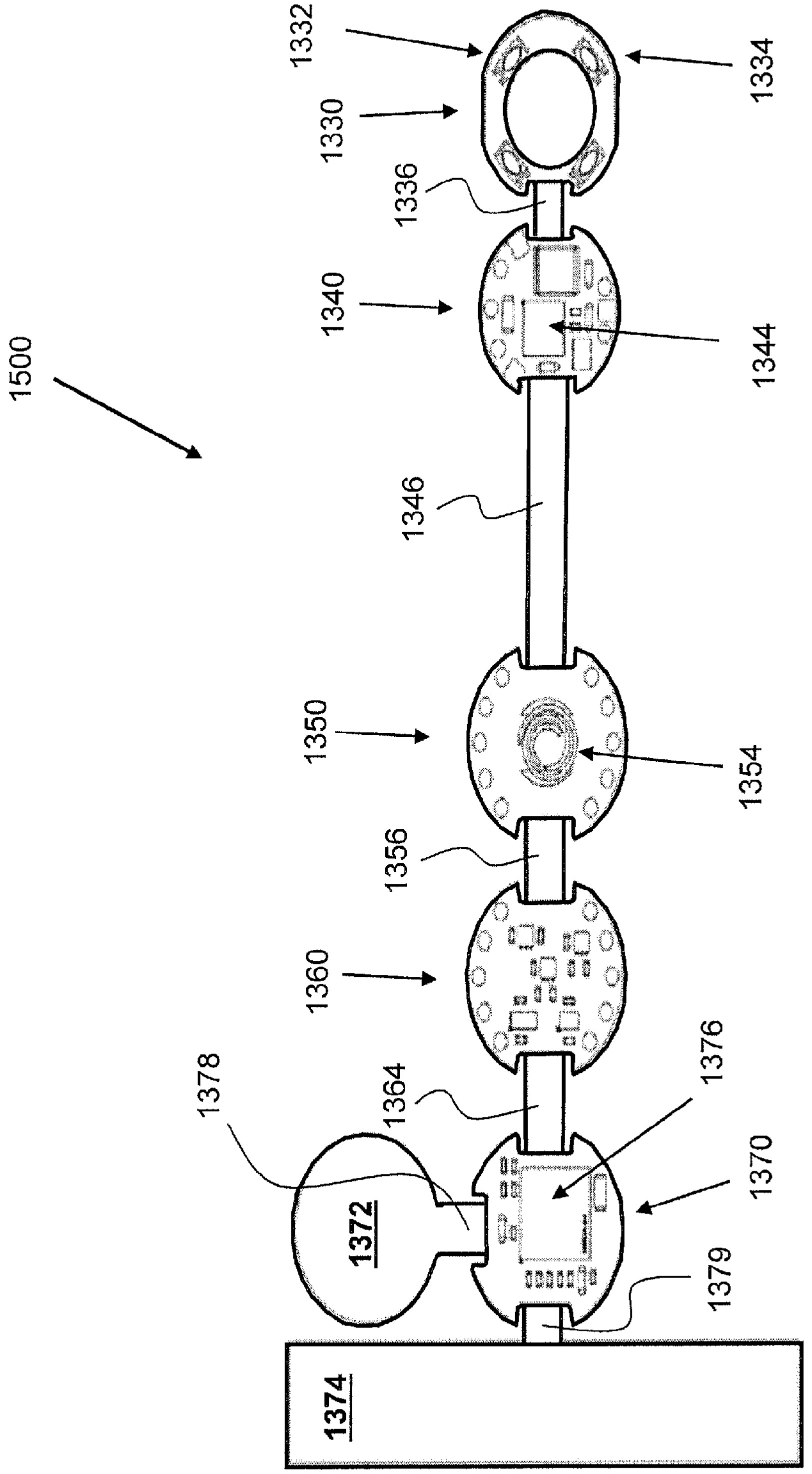
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Fig. 15B

MAGNETICALLY MANEUVERABLE IN-VIVO DEVICE

PRIOR APPLICATION DATA

[0001] The present application claims benefit of prior U.S. provisional Application Ser. No. 61/420,937, entitled "MAGNETICALLY MANEUVERABLE IN-VIVO DEVICE", filed on Dec. 8, 2010, and U.S. provisional Application Ser. No. 61/491,383, entitled "MAGNETICALLY MANEUVERABLE IN-VIVO DEVICE", filed on May 31, 2011, each incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present invention generally relates to an in-vivo device and more specifically to a magnets and sensing coils assembly for a maneuverable in-vivo device.

BACKGROUND

[0003] In-vivo measuring systems are known in the art. Some in-vivo devices/systems, which traverse the gastrointestinal ("GI") system, may include an imaging sensor, or imager, for imaging (e.g., capturing images of) the interior of the GI system. An in-vivo device may include one or more imagers. Other in-vivo devices may alternatively or additionally include a medication container and means for administering medication in the GI system. Other in-vivo devices may include means for performing surgical operations in vivo.

[0004] Autonomous in-vivo devices are devices that traverse the GI system by being pushed through the GI system by peristaltic force exerted by the digestive system. Autonomous in-vivo devices may also spasmodically move in the intestinal tract in 'fits and starts'. Moving a device in vivo by using a peristaltic force has drawbacks. For example, the in-vivo device may get stuck somewhere in the GI system for an unknown period of time; the device may capture images in one direction while a nearby area, which may be clinically more interesting, is not imaged sufficiently or at all.

[0005] In addition, due to the length of the intestinal tract (several meters), it takes an in-vivo device several hours to traverse the entire GI system. In order to minimize discomfort to a patient and to allow her/him to have as normal life as possible during that time, the patient is asked to wear a data recorder for recording the images captured in vivo, in order for them to be analyzed at a later stage (e.g., after the in-vivo device is finally pushed out of the GI). When a physician reviews the images, or a selection thereof, s/he cannot be certain that all the clinically interesting, or intended, areas of the GI system were imaged. In general, the shorter the time an in-vivo device stays in the GI system, the better (e.g., to reduce discomfort to the patient).

[0006] Due to the anatomically-inhomogeneous nature of the GI system—it has anatomically distinct sections such as the small bowel and the colon—and/or to different susceptibility of its various sections to diseases, indiscriminately handling large number of images and frames by the in-vivo device is oftentimes superfluous. In part, this is because relatively less susceptible areas of the intestinal tract are overly imaged. More susceptible areas of the intestinal tract, on the other hand, may be imaged sparingly. The number of images captured from susceptible areas of the intestinal tract may be smaller than clinically desired. It may often be desirable to examine only one specific part of the GI tract, for example, the small bowel ("SB"), the colon, gastric regions, or the esophagus.

[0007] While moving an in-vivo device through the GI is beneficial, there are some drawbacks associated with autonomous in-vivo devices in the GI tract. It would be beneficial to have a full control over such movement, including maneuvering the in-vivo device to a desired location and/or orientation and/or angular position or state in the GI system, and maintaining the location/orientation/angular position or state for as long as required or needed.

SUMMARY OF EMBODIMENTS OF THE INVENTION

[0008] It would, therefore, be beneficial to be able to provide an in-vivo device that would be controllably maneuverable to a desired location and orientation, for example, in the GI system.

[0009] An in-vivo device includes a magnetic steering unit ("MSU") to facilitate maneuvering of the in-vivo device by an externally generated electromagnetic field. The MSU may include a permanent magnets assembly ("PMA") for interacting with the magnetic field to thereby produce a propelling magnetic force and/or a repelling magnetic force and/or a rotational force, for steering and rotating the in-vivo device. The PMA may include one permanent magnet, or a set of permanent magnets. A permanent magnet may be a ring, or it may be annular or ring-like shaped. The MSU may also include a magnets carrying assembly ("MCA") that is designed to hold, accommodate, carry or support the permanent magnet or magnets. The MCA may also be designed such that an electromagnetic field may induce eddy currents on the MCA that are sufficient to generate the required repelling force. That is, the MCA may be designed to generate eddy currents as a result of an applied electromagnetic field.

[0010] The in-vivo device may also include a multilayered imaging and sensing printed circuit board ("MISP"). The MISP may include circuitry for capturing images, for example, of the GI system, and for transmitting images to an external data recorder. The MISP may also include a sensing coil assembly ("SCA") for sensing electromagnetic fields in order to facilitate sensing, or determination, of a current location and/or current orientation and/or angular position or state of the in-vivo device. The SCA, which may be part of the MSU, may include one or more (e.g., two, three, etc.) electromagnetic field sensors (e.g., sensing coils) that may be disposed, for example, on one or more printed circuit boards (PCBs). The SCA may include a magnetic field sensing ("MFS") section that may have embedded or formed therein some of the electromagnetic field sensing coils; other one or more electromagnetic field sensing coils may be included or formed in other PCB sections that may be structurally separated from the MFS section.

[0011] A transmitter transmitting the images, or a separate transmitter that may be mounted, for example, on, or be part of, the MISP or SCA, may transmit data that represents location and/or orientation and/or angular position of the in-vivo device to an external system (e.g., to an external maneuvering system) in order to enable the external system to generate a steering magnetic field to move the in-vivo device from a current location/orientation/angular position to a target (e.g., next required or desired) location/orientation/angular position, or to keep the in-vivo device in a certain or given location and/or orientation and/or angular position for as long as required.

[0012] In some embodiments, there may be full or some degree of structural and cylindrical/annular overlapping between the MFS section, when folded to a cylindrical shape, and the PMA. For example, the MFS section and the PMA may overlap fully (100%), or partly (less than 100%, e.g., 60%, 30%, etc.). In another embodiment, there may be no overlapping (0% overlapping) between the MFS section and the PMA.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Various exemplary embodiments are illustrated in the accompanying figures with the intent that these examples not be restrictive. It will be appreciated that for simplicity and clarity of the illustration, elements shown in the figures referenced below are not necessarily drawn to scale. Also, where considered appropriate, reference numerals may be repeated among the figures to indicate like, corresponding or analogous elements. Of the accompanying figures:

[0014] FIG. **1** is a block diagram of an in-vivo device maneuvering system according to an example embodiment;

[0015] FIG. **2** is a block diagram of an in-vivo device according to an example embodiment;

[0016] FIG. **3**A shows a spread out multilayered imaging and sensing printed circuit board (MISP) according to an example embodiment;

[0017] FIG. **3**B shows another side of the MISP of FIG. **3**B;

[0018] FIG. **3**C shows a partial in-vivo device with the MISP of FIGS. **3**A and **3**B cylindrically folded according to an example embodiment;

[0019] FIG. **3**D shows the in-vivo device of FIG. **3**C with an optical head according to an example embodiment;

[0020] FIG. **4**A is a cross-sectional view of a flat sensing coil according to an example embodiment;

[0021] FIG. **4**B is a cross-sectional view of a flat sensing coil according to another example embodiment;

[0022] FIG. **5** shows five layers of a multilayered sensing coils PCB according to an example embodiment;

[0023] FIG. **6**A shows three annular permanent magnets for inducing a force for propelling and/or rotating an in-vivo device according to another example embodiment;

[0024] FIG. **6**B shows two eddy current plates for inducing a force for repelling an in-vivo device according to another example embodiment;

[0025] FIG. **7**A shows a hollow conductive cylindrical structure for inducing eddy current according to an example embodiment;

[0026] FIG. **7**B shows an eddy current annular disc according to an example embodiment;

[0027] FIG. **7**C shows an eddy current disc according to an example embodiment;

[0028] FIG. **7**D shows a magnets carrying assembly (MCA) according to an example embodiment;

[0029] FIG. **7**E shows a cross-sectional view of the MCA of FIG. **7**D;

[0030] FIG. **7**F shows the MCA of FIG. **7**D with three permanent magnets mounted thereon;

[0031] FIG. **7**G shows an MCA according to another example embodiment;

[0032] FIG. **7**H shows an MCA according to yet another example embodiment;

[0033] FIG. **8** shows a multilayered imaging and sensing PCB (MISP) according to an example embodiment;

[0034] FIG. **9**A shows the MISP of FIG. **8** introverted or ingathered according to an example embodiment;

[0035] FIG. **9**B shows the MISP of FIG. **8** in its folded/introverted state and, in addition, a magnet assembly according to an example embodiment;

[0036] FIG. **10**A shows a cross-sectional view of an in-vivo device with a magnetic steering unit (MSU) according to an example embodiment;

[0037] FIG. **10**B shows a general view of the in-vivo device of FIG. **10**A, where the SCA wraps a PMA according to an example embodiment;

[0038] FIG. **11** shows an example magnetic field generating system for maneuvering an in-vivo device according to an example embodiment;

[0039] FIG. **12** illustrates an example vector representation of a magnetic field generated by a maneuvering magnetic field generating system according to an example embodiment;

[0040] FIGS. **13**A and **13**B show different cross-sectional views of an in-vivo device in which the MFS section of the SCA and the PMA do not overlap according to an example embodiment;

[0041] FIG. **14** shows a general view of the in-vivo device of FIGS. **13**A-**13**B according to an example embodiment; and

[0042] FIGS. **15**A and **15**B show two perspectives of a spread out multilayered imaging and sensing PCB (MISP) of the in-vivo device of FIGS. **13**A, **13**B, and **14** according to an example embodiment.

DETAILED DESCRIPTION

[0043] The description that follows provides various details of exemplary embodiments. However, this description is not intended to limit the scope of the claims but instead to explain various principles of the invention and the manner of practicing it.

[0044] In general, when an autonomous in-vivo device traverses the GI system, the faster the in-vivo device moves through a particular section of the GI system, the more pictures are required to be transmitted from the in-vivo device per unit of time in order to maintain a reasonable distance between GI sites for which successive pictures are taken. That is, if the in-vivo device is at rest, the pictures capturing rate, or image frames generation and/or transmission rate can be made relatively low without risking losing clinical information, and if it moves along the GI system, the pictures/frames generation/transmission rate should be higher in order to take approximately the same number of pictures per unit length. Therefore, some in-vivo imaging systems use a movement estimator for assessing the movement of in-vivo devices in order to enable the imaging systems to deduce the required image capturing rate. For example, in order not to waste physical space in the in-vivo device on a dedicated movement sensing device (e.g., accelerometer) and on the circuitry required to operate it, images captured by the in-vivo device are used to provide the movement indications. However, having full control over the location, orientation and angular position of an in-vivo device in the GI system renders the above-mentioned, and similar, frame rate changing solutions unnecessary, and, in general, such control has many advantages. By “orientation of the in-vivo device” is meant the spatial direction of the longitudinal axis of the in-vivo device, and changing the angular position or state of the in-vivo device from one angular position or state to another may be obtained by rotating the in-vivo device about its longitudinal axis or about any other axis of the in-vivo device.

[0045] FIG. **1** is a block diagram of a system for magnetically maneuvering an imaging device in vivo, for example for maneuvering an in-vivo imager in the GI system. The system may include a maneuverable in-vivo imaging device **110** for capturing images (i.e., taking pictures) in vivo, and for transmitting the images/pictures; a data recorder and antenna assembly **120** for receiving and processing the images transmitted from in-vivo device **110** and (optionally) for transferring instructions to imaging device **110** (e.g., to change a mode of operation; e.g., to change the images capturing rate), and for transferring the images to a workstation; a user workstation **130** for receiving the images—and optionally, metadata related, for example, to the images—from data recorder **120**, and for displaying selected images or a video clip compiled from such images, e.g., to an operator or physician. In-vivo imaging device **110** may include a magnetic steering unit (MSU), which is not shown in FIG. **1**, that is capable of sensing three types of magnetic fields: one type of magnetic field for magnetically inducing location and/or orientation and/or angular position signals in imaging device **110**, another type of magnetic field for magnetically inducing maneuvering forces for maneuvering imaging device **110**, and a third type of magnetic field for externally transferring electrical energy to an energy-picking/harvesting element/circuit in the in-vivo device. Steering of imaging device **110** may be controlled based on the location/orientation/angular position signals.

[0046] The system may also include a magnetic maneuvering unit ("MMU") **140** for generating the magnetic fields that induce the location/orientation/angular position signals in imaging device **110**, for interpreting the corresponding location/orientation/angular position data transmitted from imaging device **110**, and for generating a magnetic field to steer imaging device **110** to a desired location/orientation/angular position and, if desired or required, for generating the magnetic fields that induce electrical power in imaging device **110**.

[0047] MMU **140** may include a device displacement module ("DDM") **150** for translating an intended (e.g., next) location and/or orientation and/or angular position of in-vivo device **110** into a magnetic steering force to position imaging device **110** in the next desired position and/or orientation and/or angular position. MMU **140** may also include AC/DC power amplifiers **160** for generating the electrical signals **162** required to generate the three types of magnetic fields (one for magnetically inducing location and/or orientation and/or angular position signals, the other for generating the steering/rotational force, and the third for transmitting energy). MMU **140** may also include AC coils and DC coils **170** for generating the required magnetic fields from electrical signals **162**. MMU **140** may include fiducial electromagnetic sensors **180** for producing an output signal (e.g., current or voltage) that represents or embodies a reference coordinates system relative to which the position and/or orientation of in-vivo device **110** may be sensed, determined, or changed.

[0048] Device displacement module (DDM) **150** may include sensors interpreter **152** for interpreting location signals and orientation signals originating from the magnetic steering unit (MSU) of in-vivo imaging device **110** and signals originating from fiducial sensors **180**. DDM **150** may also include a location/direction regulator **154** for outputting a regulating signal to AC/DC power amplifiers **160** to generate magnetic fields that correct an 'error' in the location, and/or an error in the orientation, of in-vivo device **110**. By "error in the location of in-vivo device **110**" is meant a difference between a currently sensed location of in-vivo device **110** and a next location of the in-vivo device. By "error in the orientation of in-vivo device **110**" is meant a difference between a currently sensed orientation of in-vivo device **110** and a next orientation of the in-vivo device. Data representing or related to the currently sensed location and/or orientation of in-vivo device **100** is shown at **124**, and it may be provided to DDM **150**, for example from data recorder **120**. Data **132** representing or regarding the next location and/or next orientation of the in-vivo device may be provided to DDM **150**, for example from a user-operable joystick connected to, or that is part of, user workstation **130**.

[0049] After in-vivo imaging device **110** is swallowed, or otherwise ingested, it may start capturing images of the GI system, generate an image frame for each captured image, and transmit **112** the image frames to data recorder **120**. In order for magnetic maneuvering unit (MMU) **140** to guide and control in-vivo device **110** in the GI system the location and orientation of the device has to be known in real-time. In order to know that, workstation **150** outputs a command **158** to AC/DC power amplifiers **160** to activate/operate coils **170** that generate electromagnetic field **172** to induce electromagnetic signals in device **110** (and, optionally, also in fiducial sensors **180**), that indicate, or facilitate sensing of, the current location of in-vivo device **110**. The magnetic steering unit (MSU) of in-vivo imaging device **110** may use an on-board sensing coil assembly to sense electromagnetic field **172**, and may return a feedback signal, or feedback data, to MMU **140** (e.g., through data recorder **120**), as described below. The on-board sensing coil assembly (SCA) of in-vivo device **110** may include three mutually perpendicular, or orthogonal, electromagnetic sensing coils for sensing electromagnetic field **172**. In-vivo device **110** is configured, among other things, to transmit **112** data, which is referred to herein as "location data", "orientation data", or "angular position data" (depending on the context) that represent the output signals of the sensing coil assembly (e.g., the sensors' readout), to data recorder **120**. In other words, the signals output by the SCA, which may indicate the location and/or orientation and/or angular position of the in-vivo device, may be digitally represented by corresponding data. In one embodiment, in-vivo device **110** may transmit image frames with the location/orientation/angular position data embedded in them, or in selected image frames. In another embodiment in-vivo device **110** may transmit the location/orientation/angular position data independently of the image frames, for example by using a separate or dedicated transmitter and/or a separate communication channel.

[0050] Data recorder **120** may relay the location/orientation/angular position data to sensors interpreter **152** of workstation **150**. Fiducial sensors **180**, which also sense electromagnetic field **172**, may be attached to the patient, and/or to a bed on which the patient lies surrounded by coils **170** that generate electromagnetic field **172**. The output of fiducial sensors **180** may be also transferred to workstation **150**, and location/direction regulator **154** may deduce the location/orientation/angular position of in-vivo device **110** from the location/orientation/angular position data originating from the in-vivo device, for example, relative to a reference coordinates system that may be represented by, or embodied in, the output signal(s) of fiducial sensors **180**. Location/direction regulator **154** may also use the data originated from user workstation **130** (e.g., data **132**) originated from the in-vivo device to calculate a corrective signal and to output a corresponding command to AC/DC power amplifiers to change electromagnetic field **172** such that in-vivo device **110** would be steered/maneuvered to the intended location and/or orientation. Workstation **150** may transfer various types of data **142** to user workstation **130** for display, etc., for example location data; orientation data; force that the in-vivo imaging device exerts or applies on a tissue wall of the GI system, etc. User workstation **130** may associate images that it receives **122** from data recorder **120**, with the various types of data **142**.

[0051] FIG. **2** schematically illustrates an example in-vivo imaging system according to an embodiment. The in-vivo imaging system may include in-vivo imaging device **110**, external data recorder **120**, workstation **130** (e.g., personal computer), and a display **202**. In-vivo imaging device **110** may be, for example, a swallowable device capturing images and transmitting corresponding image frames to an external receiving apparatus, such as data recorder **120**. The image frames may be presented in real-time or after processing, be combined into an image stream or video movie for display to a user, for example using display **202**.

[0052] An in-vivo imaging device may have one or more imagers. By way of example, imaging device **110** include one imager; e.g., imager **212** (numbers of imagers other than one or two may be used, with suitable modifications to the methods discussed herein). In-vivo imaging device **110** also includes a light/illumination source **214**, a frame generator **220**, a controller **230**, a storage unit **240**, a transceiver **250**, and a power source **203** for powering them. Power source **203** may include a charge storing device (e.g., one or more batteries) with electrical circuit that jointly facilitates transfer of electrical power from an external apparatus to the in-vivo device through electromagnetic induction. Controller **230**, among other things, controllably operates illumination source **214** to illuminate areas traversed by in-vivo device **110**, and coordinates or schedules the images capturing timing of imager **212**. Imaging device **110** may also include a sensing coil assembly (SCA) **210**. Controller **230** may coordinate or schedule the reading of the output of sensing coil assembly **210** and temporarily store captured images and related image frames in storage unit **240**. Controller **230** may also perform various calculations and store calculation results in storage unit **240**.

[0053] At the time of or shortly after in-vivo imaging device **110** is swallowed, or after some predetermined delay (e.g., 2 minutes), imager **212** may start capturing images of areas of the GI system. Because natural light does not enter the intestinal tract, imager **212** does not require a light shutter, as opposed to ‘regular’ (i.e., non-swallowable) imagers. The function of the light shutter is, therefore, implemented by the darkness inside the intestinal tract and by intermittently illuminating the FOV of imager **212**. Typically, the exposure time of imager **212** is 2-3 milliseconds. Imager **212** includes an image sensor that may be, or include, an array of photo sensor elements (e.g., pixels) such as 256×256, 320×320, 1 Mega pixel or any other suitable array. Imager **212** outputs image data **213** by using a pixel format corresponding to the used pixels. For convenience, pixels are normally arranged in a regular two-dimensional grid/array. By using this kind of arrangement, many common operations can be implemented by uniformly applying the same operation to each pixel independently. Each image data represents a captured image and, optionally, additional selected portions thereof.

[0054] Frames generator **220** receives image data **213** and uses the image data to produce an image frame (“frame” for short) for the pertinent captured image. A frame typically includes a header field that contains information and/or metadata related to the frame itself (e.g., information identifying the frame, the serial number of the frame, the time the frame, the bit-wise length of the frame, etc.). A frame may also include an uncompressed version of the image data and/or a compressed version thereof, and a decimated image. The header may also include additional information, for example readout of sensing coil assembly **210** or readout of any additional sensor integrated into device **110**. Controller **230** may operate illumination source **214** to illuminate, for example, four times per second to enable capturing four images per second, and transceiver **250** to concurrently transmit corresponding frames at the same rate. Controller **230** may operate illumination source **214** to capture more images per second, for example seventeen images or more than seventeen images per second, and transceiver **250** to concurrently transmit corresponding frames at the same rate. Controller **230** may operate sensing coil assembly **210** directly or through another (e.g., slave) controller, and write a corresponding sensing data (e.g., the sensing coils readout) into the corresponding frame; e.g., into a frame that is to be transmitted immediately after each sensing of the magnetic field. After frames generator **220** produces a frame for a currently captured image and writes localization data into it, controller **230** wirelessly communicates **242** the frame to data recorder **120** by using transceiver **250**. Data recorder **120** may be part of the magnetic maneuvering unit (MMU) **140** or a stand alone unit that is located close enough to the person in order to facilitate receiving and processing of the transmitted frames by data recorder **120**.

[0055] Data recorder **120** may include a transceiver **244**, a frame parser **270**, and a processor **290** for managing transceiver **244** and frame parser **270**. Data recorder **120** may include additional components (e.g., USB interface, Secure Digital (“SD”) card driver/interface, controllers, etc.), elements or units for communicating with (e.g., transferring frames, data, etc. to) both the regulator **154** of MMU **140** and the processing/displaying system that are configured to process the images captured, and the localization information sensed, by in-vivo device **110**, and related data. In one embodiment transceiver **244** receives a frame corresponding to a particular captured image, and frame parser **270** parses the frame to extract the various data entities contained therein (e.g., image data, decimated image associated with, or representing the particular captured image, etc.). In another embodiment, some frames, which are referred to herein as “localization frames”, may be dedicated to carrying or transferring localization data, meaning that such frames may include localization data and, optionally, metadata related to the localization data, but not image data. Using localization frames in addition to image frames that may include both image data and localization data enables reading the localization data (e.g., the output of the sensing coils assembly **210**) at a rate that is higher than the images capturing rate. For example, n (n=1, 2, 3, . . .) localization frames may be transmitted (e.g., by being inserted) between two consecutive image frames, where, in this case, by “image frame” is meant a frame that includes image data and localization data.

[0056] The in-vivo imaging system of FIG. **2** may include a workstation **130**. Workstation **130** may include a display or be functionally connected to one or more external displays, for example to display **202**. Workstation **130** may receive frames (e.g., image frames, localization frames) from data recorder **120** and present them in real-time, for example as live video, or produce a video stream that also contains location and orientation information that may also be displayed on, for example, display **202**. Workstation **130** may include a memory, such as memory **204**, for storing the frames transferred from data recorder **120**, and a processor, such as processor **205**, for processing the stored frames. In-vivo imaging device **110** may also include a magnetic steering unit (MSU) **272**. MSU **272** may include a sensing coil assembly (SCA) **210** and a permanent magnets assembly (PMA) **211**. In-vivo imaging device **110** may also include an "on/off" switching system **215** for switching imaging device **110** on and off.

[0057] In some embodiments, data representing the output of sensing coils assembly **210** may be transmitted to data recorder **120** by using image frames, and optionally by using also dedicated frames. The data representing the output of sensing coils assembly (SCA) **210** is (also) referred to herein as "localization data" or "sensing data". In other embodiments, in-vivo device **110** may use a dedicated narrow-bandwidth telemetry channel to transmit the localization data to data recorder **120**. The bit rate of the telemetry channel may be a few hundreds of Kilo bits per second (KBPS) (e.g., between 50 KBPS and 500 KBPS). In order to facilitate the dedicated narrow-bandwidth telemetry channel, transceiver **250** of in-vivo device **110** may include an additional transmitter which is not shown in FIG. **2**, and the transceiver **144** of data recorder **120** may include an additional receiver, which is not shown in FIG. **2**. In some embodiments, in-vivo device **110** may include two 3-dimensional accelerometers for measuring the direction in which the in-vivo device moves, and the orientation of the in-vivo device.

[0058] FIGS. **3**A through **3**B depict a cross-like multilayered imaging and sensing printed circuit board (MISP) **300** of an in-vivo device similar to in-vivo imaging device **110**, according to an example embodiment. MISP **300** may be rigid-flex, which means that portions/parts/sections thereof may be rigid whereas other portions, parts or sections thereof may be flexible enough to allow them to be folded into a cylinder-like structure. MISP **300** may be full-flex, which means that all of its portions/parts/sections are flexible. By way of example, MISP **300** is shown including two PCB sections that 'cross', or intersect, each other: section **340** and section **350**. PCB section **340**, which may be rigid-flex, may be regarded as an "imaging section" because it includes the imaging circuitry **306**. PCB section **350**, which may be fully flexible, may be regarded as a magnetic field sensing (MFS) section because it includes a set of electromagnetic sensing coils for sensing electromagnetic fields by which the current location and/or current orientation and/or current angular position of the in-vivo imaging device may be determined or evaluated. MFS **350** may be part of a sensing coils assembly (SCA) of the MISP **300**. The SCA may include one or more additional PCB sections (e.g., PCB section **302**) that may include additional electromagnetic field sensing coils (e.g., sensing coil **330**).

[0059] MISP **300** may include 1-layer portions or sections even though it is generally referred to as a 'multilayered' PCB. PCB section **340** may include three rigid sections, designated as **302**, **304** and **306**, that may be multilayered, and two flexible sections, designated as **394** and **396**, that may also be multilayered. Flexible section **394** may connect rigid sections/portions **304** and **306** and be partly sandwiched between layers of these sections/portions. Section **396** may connect rigid sections **302** and **304** and be partly sandwiched between layers of these sections.

[0060] Referring to FIG. **3**A, an imager **360**, which may be similar to imager **212** of imaging device **110**, may be mounted on rigid section **306**. An illumination source similar to illumination source **214** of in-vivo device **110** may also be mounted on rigid section **306**, as shown at **370**. By way of example, the illumination source mounted on rigid section **306** includes four light sources which are equidistantly, circle-wise, positioned on rigid section **306**. Other electronic components of the in-vivo device (e.g., ASIC, controller, transmitter, crystal oscillator, memory, etc.), may be mounted on section **304** and/or on section **302**. An electromagnetic field sensing coil **330** may be mounted on, or be embedded or incorporated into, or formed in PCB rigid section **302**. Electromagnetic field sensing coil **330** may functionally be regarded as part, or an extension, of MFS section **350**. MFS section **350** and PCB section **302** with electromagnetic field sensing coil **330**, thus, form an SCA. In general, an SCA may include, or have disposed thereon, one or more electromagnetic field sensors (e.g., sensing coils, etc.) that may be disposed on one or more PCB sections, and at least one of the one or more PCB sections may be foldable, for example cylindrically or to form a cylinder, while other PCB sections of the SCA may be rigid or partly flexible. The at least one of the one or more PCB sections may be foldable to make the electromagnetic field sensors mutually perpendicular. By "partly flexible" is meant flexible but not cylindrically foldable. The other side of sections **302**, **304**, and **306** may also hold or accommodate additional elements and/or components, as demonstrated in FIG. **3**B. Referring to FIG. **3**B, section **302** may hold, include, or accommodate an antenna **380** to facilitate radio frequency (RF) communication between the in-vivo imaging device and the data recorder with which the in-vivo imaging device operates.

[0061] Sections **304** and **306** may respectively hold, include, or accommodate electrical springs **390** and **392**. Section **340** is shown in FIGS. **3**A and **3**B outspread, but, as part of the in-vivo device assembly process, it is folded such that the rigid sections thereof are stacked in a parallel manner such that rigid sections **304** and **306** can hold, there between, one or more batteries, and the lines normal to the planes of sections **304** and **306** coincide with a longitudinal axis of the in-vivo imaging device. Electrical springs **390** and **392** secure the one or more batteries in place, and electrically connect them to the imaging device's electrical circuit.

[0062] Turning again to FIG. **3**A, magnetic field sensing (MFS) section **350**, which may be part of the SCA, may include electromagnetic sensing coil **310** and electromagnetic sensing coil **320**. Electromagnetic sensing coil **310** and electromagnetic sensing coil **320** are shown to be rectangular, but they need not be rectangular. The two sensing coils **310** are collectively referred to as sensing coil **310** because the two sensing coils **310** are electrically, or functionally, interconnected, as shown, for example, in FIG. **5**, and thus they form one electrical component (i.e., one sensing coil). Likewise, the two coils **320** are collectively referred to as sensing coil **320** because the two coils **320** may be electrically, or functionally, interconnected, as shown, for example, in FIG. **5**, and thus they may form one sensing coil.

[0063] Reference numeral **308** designates a flexible multilayered PCB dielectric substrate that holds, includes, or accommodates sensing coils **310** and **320**. Each PCB layer of flexible multilayered PCB substrate **308** may hold, include, or accommodate some of the coil turns of sensing coils **310** and/or some of the coil turns of sensing coils **320**. Example layers of a flexible multilayered PCB substrate are shown in FIG. **5**, which is described below. Magnetic field sensing (MFS) section **350** is shown in FIGS. **3**A and **3**B outspread, and cylindrically folding it places some turns of sensing coils **310** against other turns of sensing coils **310** such that their normal lines substantially coincide with a same axis (e.g., the 'X' axis of the X-Y-Z coordinates system), and some turns of sensing coils **320** against other turns of sensing coils **320** such that their normal lines substantially coincide with another same axis (e.g., the 'Y' axis of the X-Y-Z coordinates system). FIG. **3**C shows a partly assembled in-vivo imaging device with the folded/introverted multilayered PCB section **340** and the cylindrically folded multilayered MFS section **350**. FIG. **3**D shows the partly assembled in-vivo device of FIG. **3**C with an optical head **362** mounted on top of imager **360** and illuminating source **370**.

[0064] FIG. **4**A shows an example cross-sectional area of a sensing coil similar to sensing coil **330** according to an example embodiment. Assume that rigid section **302** of FIG. **3**A includes four layers that hold, include, or accommodate the electrical wire/conductors that make up sensing coil **330**. Also assume that: the average coil area is 38 mm2; the conductor width is 50 micrometer (μm), and the gap between adjacent conductors is also 50 μm. The overall coil winding, Nt, may, then, be calculated by using formula [1]:

$$Nt=n\times L=30\times 4=120 \qquad [1]$$

[0065] where n is the number of coil turns per layer and L is the number of layers of multilayered rigid section **302**.

[0066] Also assume that the maximum magnetic field, Bmax, applied to sensing coil **330** is 400 Gauss, and the magnetic field is sinusoidally oscillating at **4** KHz.

[0067] The maximum voltage that a sensing coil outputs when placed in a magnetic field may be calculated by using formula [2]:

$$V=\frac{d}{dt}B(t)\cdot A_{Effective}\left(\hat{n}\cdot\hat{B}=1\right) \qquad [2]$$

[0068] where B(t) is the magnetic field (vector), in Tesla, applied on the sensing coil; A is the coil's area in square meter [m^2]; and n̂ is the coil direction (it is a unit vector that has no physical units)—i.e., it is a direction normal to the coil's area.

[0069] Given the above-mentioned specifics of sensing coil **330** and using formula [2], the theoretical maximum voltage that coil **330** would output is:

$$|VMAX|=0.04[\text{Gauss}]*2\pi*4{,}000[\text{Hz}]*1*38*120*10^{-6}=4.58[\text{V}] \qquad [3]$$

[0070] FIG. **4**B shows an example cross-sectional area of a sensing coil similar to sensing coils **310**, **320** according to an example embodiment. Assume that section **350** of FIG. **3**A includes four layers that hold, include, or accommodate the electrical wires/conductors that make up sensing coils **310**, **320**. Also assume that: the average coil area is 32 mm2 (8 mm×4 mm); the conductor width is 50 micrometer (μm), and the gap between adjacent conductors is also 50 μm. The overall coil winding of each of coils **310** and **320**, Nt, may be calculated by using formula [1] above:

$$Nt=20\times 4\ (\text{layers})\times 2\ (\text{opposing sides})=160 \qquad [4]$$

[0071] Also assume that the maximum magnetic field, Bmax, applied to sensing coils **310**, **320** is 400 Gauss, and the magnetic field is sinusoidally oscillating at **4** KHz.

[0072] Given the above-mentioned specifics of sensing coils **310** and **320**, and using formula [2] above, the theoretical maximum voltage that each of coils **310** and **320** would output is:

$$|VMAX|=0.04[\text{Gauss}]*2\pi*4{,}000[\text{Hz}]*1*32*160*10^{-6}=5.15[\text{V}] \qquad [5]$$

[0073] Since section **350**, with the coil turns on it, is folded to form a cylindrical structure, a correction factor may be used to compensate for the deviation from the plane of the coil turns. The maximum voltage that each of coils **310** and **320** would output after factoring in the curvature of section **350** is:

$$|VMAX|=5.15*2*\sqrt{2}/\pi=4.6[\text{V}] \qquad [6]$$

[0074] Another factor that reduces the voltage induced in coils **310** and **320**, and therefore is to be taken into account, is the eddy current that each coil turn develops as a result of the external AC magnetic. An advantage of the external AC magnetic field is that it induces eddy currents for repelling and restraining the in-vivo device while the device is maneuvered. However, the same AC magnetic field also induces eddy currents in the coils' turns that are harmful because these currents attenuate the voltage induced in the coils' turns. Therefore, equations 3 and 5 are required to be modified to accommodate for the attenuation caused by the eddy current. The attenuation factor was empirically found to be between 2 to 8.

[0075] FIG. **5** shows an exploded view of layers of an example multilayered magnetic field sensing (MFS) section **400** according to an example embodiment. By way of example, MFS section **400** includes PCB layers **402**, **404**, **406**, **408**, and **409**. MFS section **400** hold, include, or accommodates three electromagnetic sensing coils: coil #**1** (shown at **410**), coil #**2** (shown at **420**), and coil #**3** (at **430** though not shown). PCB layers **402**, **404**, **406**, **408**, and **409** are electrically, or functionally, interconnected by using micro vias, which are shown at **440** exaggeratedly long, for clarity. (A "via" is a through-connection electrically connecting between different layers of a printed circuit board.) Layer **409** is a ground/common layer. By using several layers, the overall inductance, and thus the sensitivity, of electromagnetic sensing coils **410** and **420** can be increased, depending, among other things, on the number of coil turns on each layer and on the number of layers holding, including, or accommodating the coil turns.

[0076] When the sensing coils assembly (e.g., MFS section **400**) is connected to a voltmeter and subjected to a magnetic field, the voltage at the output of the sensing coils assembly can be accurately determined and, there from, the intensity of the magnetic field. Comparison, by the magnetic maneuvering unit (MMU) **140**, between the calculated magnetic field and a known map of the magnetic field can be used to calculate the location and orientation of the device. Alternatively, a sensing coils assembly similar to MFS section **400** may be connected to a low impedance device, such as rechargeable batteries or capacitor(s) in order to activate or charge it. An electrical current induced in the sensing coils may be used to charge the batteries or the capacitor and, in doing so, to 'harvest' power from external coils **170**. Alternatively, a separate coil may circumferentially be disposed on the magnets carrying assembly (MCA) or on one of the permanent magnets that is disposed on the MCA, which is dedicated to picking up energy from an external AC magnetic field.

[0077] FIG. **6**A shows a conceptual permanent magnets setup **602** for steering an in-vivo device **500** in an external DC magnetic field. In-vivo device **500** may be similar to in-vivo device **110** of FIG. **2**. Permanent magnets setup **602** may include a permanent magnet PM**1**, shown at **610**, a permanent magnet PM**2**, shown at **620**, and a permanent magnet PM**3**, shown at **630**. Magnets PM**1**, PM**2**, and PM**3**, which are ferrous-conductive elements, may be uniquely magnetized such that in-vivo device **600**, a magnetically guided device, is driven by electromagnetic propulsion interaction between external DC magnetic field and permanent magnets PM**1**, PM**2**, and PM**3**.

[0078] An external DC magnetic field would force permanent magnets PM**1**, PM**2**, and PM**3**, and therefore in-vivo device **600**, to move in a desired direction, for example in the 'Z' direction, which may be the direction coinciding with the longitudinal axis **640** of in-vivo device **600**, or to apply a torque to rotate in-vivo device **600** to a desired orientation. Variable AC and DC magnetic fields generated externally to the patient (e.g., by magnetic maneuvering unit (MMU) **140**) may provide the magnetic forces and rotational torques required to move in-vivo device **600**, and to tilt and rotate it within the GI system, based on commands issued by an operator of the magnetic maneuvering system.

[0079] Referring to FIG. **6**B, an external AC magnetic field system may induce eddy current in 'eddy-current plates' **650** and **660** that will result in repulsive forces that moderate, suppress or stabilize the propulsion dynamics resulting from, or associated with, the operation of permanent magnets PM**1**, PM**2**, and PM**3**.

[0080] The permanent magnets shown in FIG. **6**A and the eddy-current plates shown in FIG. **6**B are illustrative. Since the in-vivo device (e.g., in-vivo device **110**) has a little space to accommodate the imaging circuit, which includes the imager, transmitter, etc., the permanent magnets, the eddy-current plates, and the sensing coils, the in-vivo device has to be meticulously designed, both mechanically and electrically, in order to enable all the components of the in-vivo device to mechanically coexist in the in-vivo device's housing and to operate without interfering with one another—for example without the RF communication between the in-vivo device and the data recorder affecting the maneuvering magnetic fields and the sensing magnetic fields, and vice versa; and without one type of magnetic field (e.g., the sensing magnetic field) affecting the other type of magnetic field (e.g., maneuvering magnetic field); and without one component (e.g., the permanent magnets) functionally screening or blocking another component (e.g., the sensing coils), etc. Since the imaging section and the MFS section of the magnetic imaging and sensing printed circuit board (MISP) have to be folded into the in-vivo device's housing without entangling with the other components of the in-vivo device, the layout of the MISP and the selection of the components mounted on the MISP are subject to stringent design constraints.

[0081] An in-vivo device such as the one disclosed herein may be useful in promoting medical diagnostic procedures or other procedural operations that require or can use in vivo steering of an in-vivo device, for example through the GI system. An in-vivo device (e.g., in-vivo device **600**) may be provided with at least two permanent magnetic rings (which are also referred to herein as "permanent annular magnets"), or disks or plates, each of which may have anisotropic magnetic properties.

[0082] FIGS. **7**A, **7**B, and **7**C respectively show an electrically conductive tubular object **710** for inducing eddy current thereon when tubular object **710** is placed in an AC magnetic field, an electrically conductive annular disc **720**, and an electrically conductive disc **730**. Conductive electrically conductive tubular object **710**, conductive annular discs similar to annular disc **720**, and conductive discs similar to conductive disc **730** make up a magnets carrier assembly (MCA) **700**, which is shown in FIG. **7**D.

[0083] When an AC magnetic field is applied to tubular object **710**, annular disc **720** and disc **730**, eddy currents flow on the surface of these objects. A slit **712** disconnects the electrical continuity of these elements in order to reduce parasitic currents. Without slit **712**, the eddy currents induced by the external AC magnetic filed may induce adversary eddy currents that may degrade the efficiency of MCA **700** as it is levitated, or otherwise maneuvered, under the pertinent laws of physics (e.g., Lenz's Law).

[0084] More than one slit may be used: FIG. **6**B shows two eddy current plates **650** and **660** that are separated by two slits; in other embodiments other slits may be used. The slits setup (e.g., number of slits, their shape and relative location/orientation) may be chosen such that the repulsive force caused by or resulting from the eddy current is optimized. Magnets carrier assembly (MCA) **700** of FIG. **7**D is an electrical conductor. MCA **700** may be made entirely of silver, or aluminum, or copper, or any other suitable electrically conducting material. Alternatively, MCA **700** may be made partly of silver, partly of aluminum, etc. For example, tubular object **710** may be made of silver and the other parts of MCA **700** (e.g., conducting annular discs, conducting discs) may be made of aluminum. Alternatively, MCA **700**, or parts thereof, may be an electrically conducting alloy.

[0085] In general, MCA **700** may serve three purposes: (1) holding or accommodating the (annular, ring or ring like) permanent magnets (e.g., PM**1**, PM**2**, PM**3** of FIG. **6**A) required/used to propel the in-vivo imaging device through the GI system by using a DC magnetic field, (2) facilitating generation of the surface eddy currents that exert a repulsive/restraining/drag forces on the imaging device, and (3) housing the batteries of the in-vivo device. FIG. **7**D shows a 3-dimensional view of MCA **700**. The design of MCA **700** factors in various mechanical and operational/functional constraints, for example as mentioned above. A cross-sectional view of MCA **700** is shown in FIG. **7**E. FIG. **7**E also shows two batteries **740** of in-vivo device. FIG. **7**F shows a complete magnets assembly **780** that includes MCA **700** of FIG. **7**D and three annular permanent magnets **750**, **760**, and **770** that are mounted on MCA **700**.

[0086] Turning again to FIG. **7**E, by way of example four electrically conductive annular discs **720** are used for augmenting/enhancing the induced eddy current. As shown in FIG. **7**E, annular conductive discs **720** are perpendicularly disposed on the peripheral surface of conductive tubular object **710** to circumferentially form, in this example, three open annular channels **722**, **724**, and **726** on the periphery around conductive tubular object **710**. Open annular channels **722**, **724**, and **726** are used to hold or accommodate permanent annular magnets, or permanent magnetic rings, **750**, **760**, and **770**, respectively, as shown in FIG. **7**F. The number of annular open channels may be three, less than three, or more than three. An annular open channel may include one or more permanent magnet. By way of example, each annular open channel in FIG. 7F includes one permanent magnet. Annular conductive discs **720** in FIG. 7E are mutually parallel; in other embodiments the annular conductive discs may be unparallel.

[0087] FIG. 7E also shows a first conductive disc **730** and a second conductive disc **732** for further augmenting/enhancing the induced eddy current. Conductive disc **730** is mounted on a first side (e.g., on the left-hand side) of conductive tubular object **710**, and conductive disc **732** is mounted on a second side (e.g., on the right-hand side) of conductive tubular object **710**. As shown in FIG. 7E, conductive discs **730** and **732** are mounted opposite one another. One or more batteries may be contained in a chamber **734** formed by conductive disc **730**, conductive disc **732**, and a portion of the inner surface **714** of conductive tubular object **710**.

[0088] An in-vivo device may be maneuvered by electromagnetic repulsion-levitation interaction between external static and time varying magnetic fields that may be generated, for example, by external AC/DC coils **170**, and any of the elements shown in FIG. **7**A through FIG. **7**F. The elements shown in FIG. **7**A through FIG. **7**F, or some of these elements, may contain uniquely magnetized ferrous-conductive materials and have anisotropic magnetic properties. These elements (e.g., elements **710**, **720**, **730**, **732**) may be made of or include materials such as NdFe and/or other highly-magnetized materials. Referring to FIG. **7**F, one or more of the permanent magnets **750**, **760**, **770** may be magnetized in a direction that is parallel to the longitudinal axis (i.e., in the axial direction) of the in-vivo device (e.g., axis **640**, shown in FIG. **6**A) and the other permanent magnet(s) may be magnetized in a radial manner in order to produce a (dual) axial-radial perpendicular field around the in-vivo device. The electrically conductive tubular object **710**, annular disc **720**, and discs **730**, **732** may be made, partly or wholly, of Silver or Aluminum to minimize resistive losses. Other super magnetic materials and conductors which provide similar magnetic and electric responses may be used.

[0089] FIG. 7G shows an MCA **790** according to another example embodiment. MCA **790** includes a through slit **791** that 'cuts' MCA **790** into two symmetrical halves. MCA **790** includes a tubular object **792**. By way of example, MCA **790** also includes two annular conducting discs **793** and **794**, each annular disc being disposed on one side of tubular object **792**, and one disc **795** that is internally disposed in the middle of cylindrical structure **792**. FIG. 7H shows an MCA **796** according to yet another example embodiment. MCA **796** is similar to MCA **790**, except that MCA **796** has a slit **797** that 'goes' only half-way through MCA **796**. Reference numerals **798** in FIGS. 7G and **799** in FIG. 7H respectively denote circumferential recesses in tubular objects **790** and **796**. Each of circumferential recesses **798** and **799** may hold or accommodate a permanent magnet and, on top of the permanent magnet, an energy-picking coil dedicated to pick up, or harvest, electrical energy through electromagnetic induction. The MCA, or selective elements thereof (e.g., the tubular object) may be slotted in a different way to obtain a desired maneuvering effect.

[0090] FIG. **8** shows a multilayered imaging and sensing PCB (MISP) **800** according to an example embodiment. Like MISP **300**, MISP **800** includes two main parts: (1) an imaging part, and (2) a sensing and energy-picking part. In general, a MISP may include a primary PCB branch, one or more secondary PCB branches that may intersect the primary PCB branch, one or more tertiary PCB branches that may intersect one or more of the secondary PCB branches, etc. By way of example, MISP **800** includes a primary PCB branch, two secondary PCB branches that intersect the primary PCB branch, and a tertiary PCB branch that intersects one of the secondary PCB branches.

[0091] The primary PCB branch may include PCB portions **810**, **820** and **860**, a PCB portion **814** that connects portions **810** and **820**, and a PCB portion **862** that connects portions **820** and **860**. A first secondary PCB branch may include PCB portions **820**, **830**, **840** and **850**, a PCB portion **832** that connects PCB portions **830** and **820**, a PCB portion **852** that connects PCB portions **850** and **820**, and, similarly, a PCB portion that connects PCB portions **840** and **820**. A second secondary PCB branch may include PCB portions **860**, **870**, **880**, a PCB portion that connects PCB portions **860** and **870**, and a PCB portion that connects PCB portions **870** and **880**. The tertiary PCB branch includes PCB portions **880**, **884**, and **890**.

[0092] Some portions of MISP **800** may be common to two or more PCB branches: PCB portion **820** is common to the primary PCB branch and the left secondary branch; PCB portion **860** is common to the primary PCB branch and the right secondary branch; and PCB portion **880** is common to the right PCB branch and the tertiary branch. The common PCB portions of MISP **800** may be thought of as 'PCB hubs', or PCB intersection hubs/points, and the PCB branches of MISP **800** may be regarded as being functionally interconnected via the intersection hubs.

[0093] Each PCB portion of MISP **800** may hold, include, or accommodate an optical and/or electrical component of the in-vivo device. For example, PCB portion **810** may hold, include, or accommodate an imager, as shown at **812**; PCB portion **820** may hold, include, or accommodate a crystal oscillator, as shown at **822**; PCB portion **830** may hold, include, or accommodate a first spring coil, as shown at **834**; PCB portion **840** may hold, include, or accommodate an RF communication antenna, as shown at **842**; PCB portion **850** may hold, include, or accommodate a light emitted diode ("LED") ring, as shown at **842** (the LED ring is shown including four LEDs, but it may include less than four LEDs or more than four LEDs); PCB portion **860** may hold, include, or accommodate a switch, as shown at **862**; PCB portion **870** may hold, include, or accommodate a second spring coil, as shown at **872**; PCB portion **880** may hold, include, or accommodate a microcontroller, as shown at **882**; PCB portion **884** may hold, include, or accommodate X-Y sensing coils (the sensing coils are not shown in FIG. **8**), for respectively sensing electromagnetic fields in the X axis and in the Y axis; PCB portion **890** may hold, include, or accommodate a Z-axis sensing coil (the sensing coil is not shown in FIG. **8**), for sensing an electromagnetic field in the Z axis, where the Z axis may coincide with the longitudinal axis of the in-vivo device.

[0094] MISP **800** may be fully flexible or partly rigid and partly flexible (i.e., it may be rigid-flex, meaning that it may include flexible portions and rigid portions). For example, each of MISP portions **810**, **820**, **830**, **840**, **850**, **860**, **870**, **880**, and **890**, may be rigid or flexible. MISP portion **884** may be flexible to enable folding it into a cylindrical shape. Each of the connection portions of MISP **800** may be flexible. Each portion of MISP **800** may have n layers (n=1, 2, 3, . . . ,), and the various circuit components mounted on the various layers may be electrically interconnected through micro vias. MISP **800** is shown contained in housing **888** of the in-vivo imaging device.

[0095] FIG. **9**A shows MISP **800** in its folded/introverted state, where like referral numbers represent like PCB section/portions in FIG. **8**. FIG. **9**B shows MISP **800** in its folded/introverted state and, in addition, a magnet assembly **886** which may be similar to magnet assembly **780** of FIG. **7**F. Referring again to FIG. **7**D, magnets carrier assembly (MCA) **700** is an electrical conductor. MCA **700** may be made entirely of silver, or aluminum, or copper. Alternatively, MCA **700** may be made partly of silver, partly of aluminum, etc. Alternatively, MCA **700** may be an electrically conducting alloy.

[0096] Since magnets carrier assembly (MCA) **700** is made of electrically conducting material(s), it may shield the sensing coils of the MISP and, therefore, degrade its performance. Therefore, as shown in FIG. **9**B, magnet assembly **886**, as a whole (the magnets with the magnets carrying assembly (MCA)), is snugly fitted to be contained in or generally circumscribed by folded/introverted MISP **800** in order to mitigate mutual interference between them.

[0097] FIG. **10**A shows a cross-sectional view of an in-vivo capsule **1000** with a magnetic steering unit (MSU) according to an example embodiment. By way of example, the MSU of in-vivo capsule **1000** includes a magnetic carrier assembly (MCA) **1010**; permanent magnets **1020**; and magnetic field sensing (MFS) section **1040**. Although MCA **1010** looks different from MCA **700** of FIG. **7**D, it functions in the same way as, and it may be replaced by, MCA **700** (with the required changes; e.g., replacing the middle permanent magnet with a larger magnet). MFS section **1040** may be identical or similar to MFS section **350** of FIG. **3**A. FIG. **10**A also shows an energy-picking coil **1030** that may be used to pick up electrical energy from an external AC magnetic field for powering in-vivo capsule **1000**.

[0098] FIG. **10**A also shows an imager **1050**, which may be similar to imager **360** of FIG. **3**A; an illumination source **1060**, which may be similar to illumination source **370** of FIG. **3**A; an optical head **1070**, which may be similar to optical head **362** of FIG. **3**D; an optical window **1080**; a communication antenna **1090**, which may be similar to communication antenna **380** of FIG. **3**B, a transceiver circuit **1092**, and batteries **1002**.

[0099] FIG. **10**B shows the in-vivo capsule **1000** of FIG. **10**A with a folded multilayered imaging and sensing printed circuit board (MISP) according to an example embodiment. Regarding FIGS. **10**A and **10**B, like reference numerals refer to like elements/components. The MISP of in-vivo capsule **1000** includes MFS section **1040**, which is shown folded; an imaging section that may be similar to imaging section **340** of FIG. **3**A. By way of example, the imaging section of in-vivo capsule **1000** includes PCB rigid sections **1001**, **1003**, and **1005** (which may respectively be similar to rigid sections **302**, **304**, and **306** of FIG. **3**A), and flexible/foldable sections **1007** and **1009** (which may be similar to sections **394** and **396** of FIG. **3**A).

[0100] FIG. **11** shows a magnetic maneuvering system **1100** according to an example embodiment. Magnetic maneuvering system **1100** includes a magnetic field generator that includes DC/AC magnetic coils **1110**, **1120**, **1130**, **1140**, **1150**, **1160**, **1170**, and **1180** to generate DC and AC magnetic fields to maneuver an in-vivo device swallowed by a patient lying on bed **1190**. The DC coils and the AC coils may form a magnetic field within the 'maneuvering space' **1195**, which resembles the magnetic field shown in FIG. **11**.

[0101] FIG. **12** is an example magnetic vector field generated by magnetic coils **1210**, **1220**, **1230**, **1240**, **1250**, and **1260**. Magnetic vortex **1280** is located at the center of the vector field **1270**. Magnetic vortex **1280** is a point, or region, from which field-vectors originate and spread out symmetrically through each of coils **1210** through **1260**. The location of magnetic vortex **1280** may be moved, and its shape set, by independently controlling the magnitude and direction of the currents flowing through the coils. Dynamic manipulation of the magnetic vector field changes the characteristics (e.g., location, direction, strength, orientation) of magnetic vortex **1280**, and thus it changes the magnetic forces resulting from the interaction between the magnetic fields and the permanent magnets and the eddy-current inducing magnets carrier assembly (e.g., MCA **700**), causing the in-vivo imaging device to move as a result of these forces.

[0102] One embodiment of the invention includes a swallowable capsule or a swalloable in-vivo device including an MSU maneuverable by an externally generated electromagnetic field. The MSU may include a PMA which interacts with the magnetic field to produce a force such as propelling force and/or a repelling force and/or a rotational force, for maneuvering/steering and/or rotating the in-vivo device. The PMA may include at least one permanent magnet, and an MCA to hold, or accommodate, the at least one permanent magnet, said MCA designed to induce eddy currents as a result of an applied electromagnetic field. The capsule or device may include an SCA for sensing electromagnetic fields in order to facilitate sensing of a current location and/or current orientation and/or current angular position of the in-vivo device. The SCA may include electromagnetic field sensing coils, for example disposed on one or more foldable printed circuit boards sections.

[0103] The examples described above (for example in connection with FIGS. **3**C-**3**D and FIGS. **10**A-**10**B) refer to a magnetic steering unit (MSU) in which the magnetic field sensing (MFS) section, when folded, and the permanent magnets assembly (PMA) fully structurally overlap cylindrically, annularly or concentrically. As explained above, an MSU may have other configurations in which the overlap between the MFS section, when folded, and the PMA is partial or non-existent. An example embodiment in which there is no structural overlap between the MFS section of the SCA and the PMA is shown in FIGS. **13**A and **13**B, and in FIG. **14**, which are described bellow. Regarding FIGS. **13**A-**13**B, FIG. **14** and FIGS. **15**A-**15**B, like reference numerals refer to like elements, components, parts, or sections.

[0104] FIG. **13**A and FIG. **13**B show different cross-sectional views of an in-vivo device in which the MFS section of the SCA and the PMA do not overlap according to another example embodiment. According to this embodiment, the MFS section of the SCA and the PMA are located in different, non-overlapping, areas, or 'sections', of in-vivo device **1300**, e.g., they are in non-overlapping areas/sections **1306** and **1308**, respectively. The MFS section and the PMA may be adjacent to each other, as demonstrated by FIG. **13**A (area/section **1306** and area/section **1308** are adjacent), and by FIGS. **13**B and **14**. In other embodiments, the MFS section and the PMA may be spaced apart (e.g., there may be a gap between them, e.g., 1-3 millimeters) with respect to a longitudinal axis **1302** of in-vivo device **1300**.

[0105] Referring to FIG. **13**A, in-vivo device **1300** may include a light transparent window **1310** which may be shaped, for example, as a dome; and an optical system **1320** that may include, for example, one or more lenses supported by a lens(es) holder. In-vivo device **1300** also includes a magnetic steering unit (MSU) to facilitate maneuvering of in-vivo device **1300**.

[0106] The MSU may include a permanent magnets assembly (PMA) for steering in-vivo device **1300**. The PMA may include a magnets carrying assembly (MCA) and one or more permanent magnets that may be held in, included in, or accommodated by the MCA. The MCA may be identical or similar to, and it may function in the same or similar manner as, for example, MCA **700** of FIG. **7**D. By way of example, the MCA of in-vivo device **1300** includes a conductive tubular object **1390** and four annular conductive discs **1392**, **1394**, **1396**, and **1396**, that are disposed on the peripheral surface of conductive tubular object **1390**.

[0107] Tubular object **1390** and four annular conductive discs **1392**, **1394**, **1396**, and **1396** circumferentially form three open annular channels on the periphery of conductive tubular object **1390**. The three open annular channels formed by the example conducting tubular object and the example four annular conductive discs are shown accommodating permanent annular magnets **1384**, **1386**, and **1386**. The number of annular open channels may be three, less than three, or more than three, and the number of annular conductive discs may change accordingly. An annular open channel may include one or more permanent magnet(s), and the width of the annular open channel may change accordingly. By way of example, each annular open channel in FIG. **13**A includes one permanent magnet. The annular conductive discs **1392**, **1394**, **1396**, and **1398** in FIG. **13**A are mutually parallel; in other embodiments the annular conductive discs may be unparallel.

[0108] In-vivo device **1300** may also include a multilayered imaging and sensing PCB (MISP) for sensing electromagnetic fields by which current location and/or current orientation and/or current angular position of the in-vivo device may be determined. The MISP may include, among other things, an SCA, for sensing electromagnetic fields, and a transmitter for transmitting data, which may correspond, for example, to or represent one or more sensed electromagnetic fields, to an external data recorder or maneuvering system. Turning back to FIG. **13**A, the MISP may include a PCB section **1330**, a PCB section **1340**, a PCB section **1350**, a PCB section **1360**, a PCB section **1370**, a PCB section **1372**, and a magnetic field sensing (MFS) section **1374**. A section of PCB sections **1330**, **1340**, **1350**, **1360**, **1370**, and **1372** may be rigid or flexible. PCB section **1372** and MFS section **1374** may form the SCA part of the MISP.

[0109] Rigid PCB sections, for example rigid PCB sections of the MISP, may be structurally and electrically interconnected by one or more flexible PCB sections. A PCB section may be multilayered, where layers thereof may be electrically interconnected through vias. The entire, part, or most of the MISP may be flexible, while the other sections or parts of the MISP may be rigid. Electrical components (e.g., image sensor(s), ASIC, transmitter, illumination sources, controller, etc.) may be mounted on various PCB sections of the MISP. For example, illumination sources **1332** and **1334** are mounted on PCB section **1330** of the MISP; an image sensor **1342** and ASIC **1344** are mounted on PCB section **1340** of the MISP, a radio frequency ("RF") operated switch **1352** and a conductive spring coil **1354** are mounted on PCB section **1350** of the MISP; various electrical components are generally shown, at **1362**, mounted on PCB section **1360** of the MISP; additional electrical components (e.g., a controller **1376**) are generally shown mounted on PCB section **1370** of the MISP.

[0110] MFS section **1374** may include (for example it may have mounted thereon, or embedded in, incorporated or formed therein) a set of electromagnetic sensing coils. PCB section **1372** may also include (for example it may have mounted thereon, or embedded in, incorporated or formed therein) an electromagnetic sensing coil that may functionally be part, or an extension, of MFS section **1374**. Signals that are induced in the electromagnetic sensing coils of MFS section **1374** and PCB section **1372** by timely generated/transmitted sensing electromagnetic fields facilitate determination of the current location and/or current orientation and/or current angular position of the in-vivo device. Such determination may be made internally, for example, by controller **1376** of in-vivo device **1300** and communicated to an external system, or externally, for example by transmitting, from the in-vivo device to an external system, data that may represent the sensing coils' output in order for the external system to deduce the in-vivo device's current location and/or orientation and/or angular position from that data.

[0111] Magnetic field sensing (MFS) section **1374** is shown folded in FIGS. **13**A-**13**B, and **14**. Folded MFS section **1374** and housing **1304** of in-vivo device **1300** may make up concentric cylinders such that a longitudinal axis of MFS section **1374** and longitudinal axis **1302** of in-vivo device **1300** may be aligned; in other embodiments the two longitudinal axes may be misaligned. MFS section **1374** may include sensing coils whose setup may be identical or similar to the sensing coils' setup shown, for example, in FIG. **3**A and described, for example, in connection with MFS **350**.

[0112] In-vivo device **1300** also includes a power source that may include one or more batteries. By way of example, the power source of in-vivo device **1300** may include two batteries: battery **1380** and battery **1382**. Batteries **1380** and **1382** may be rechargeable, for example they may be recharged by harvesting energy wirelessly; e.g., by exploiting electromagnetic radiation. Battery **1380** may be held in place between battery **1382** and PCB section **1350** by conductive spring coil **1354**.

[0113] The length, L, of in-vivo device **1300** may be, for example, about 36 millimeters (e.g., 36.3 millimeters); the diameter, D, of in-vivo device **1300** may be, for example, about 13 millimeters (e.g., 13.4 millimeters). In-vivo device **1300** may have other lengths (e.g., 33 millimeters) and other diameters (e.g., 12 millimeters). Reference numeral **1378** designates a flexible PCB section of the in-vivo device's MISP that connects PCB section **1370** to PCB section **1372**.

[0114] FIG. **13**B shows another cross-sectional view of in-vivo device **1300**. The MISP of in-vivo device **1300** may include PCB sections **1330**, **1340**, **1350**, **1360**, **1370**, **1372**, and **1374**, and flexible PCB sections that connect these PCB sections. For example, flexible PCB section **1336** connects PCB sections **1330** and **1340**; flexible PCB section **1346** connects PCB sections **1340** and **1350**; flexible PCB section **1356** connects PCB sections **1350** and **1360**; flexible PCB section **1364** connects PCB sections **1360** and **1370**; flexible PCB section **1378** (shown in FIG. **13**A) connects PCB sections **1370** and **1372**; and flexible PCB section **1379** connects

PCB sections **1370** and **1374**. The MISP of the in-vivo device is shown folded in FIGS. **13**A-**13**B, and **14**, and spread out in FIGS. **15**A and **15**B.

[0115] FIG. **14** shows a general view of the in-vivo device of FIGS. **13**A-**13**B. As can be seen in FIG. **14**, there is no overlapping between MFS section **1374** and the PMA, as each section/part is located in a different area of in-vivo device **1300**: MFS section **1374** in area **1306** and the PMA in area **1308**.

[0116] FIG. **15**A and FIG. **15**B show two perspectives of a spread out multilayered imaging and sensing PCB (MISP) **1500** of in-vivo device **1300**. In addition to the PCB sections and electrical components and circuitries mentioned above in connection with FIGS. **13**A-**13**B, MISP **1500** may also include an antenna **1510** for transmitting, for example, images that are captured by, for example, image sensor **1342**, and/or another type of data. The other type of data may be, or include, data pertaining to sensed electromagnetic fields that are used to determine the location and/or orientation and/or angular position of in-vivo device **1300**. Antenna **1510** may be a coil including, for example, 1.5 turns, and it may be embedded in PCB section **1340**, as shown in FIG. **15**A. Referring to FIG. **15**B, PCB section **1330** includes illumination sources **1332** and **1334** (e.g., LEDs), and it may include additional illumination sources.

[0117] MISP **1500** includes a primary PCB section **1520**. Primary PCB section **1520** may include PCB sections **1330**, **1340**, **1350**, **1360**, and **1370**, and the PCB sections that connect them. PCB sections **1330**, **1340**, **1350**, **1360**, and **1370** are lined up side by side, in a row. PCB section **1330**, which may include the illumination source(s) (as shown in FIG. **15**B, for example at **1332** and **1334**), may be regarded as a first/leading PCB section of the PCB sections line up, and PCB section **1370** may be regarded as a second/trailing PCB section of the PCB sections line up. MISP **1500** also includes PCB section **1372**.

[0118] MSF section **1374** may hold, include, or accommodate X-Y sensing coils (the sensing coils are not shown in FIGS. **15**A-**15**B), for respectively sensing electromagnetic fields in the X axis and in the Y axis. PCB portion **1372** may hold, include, or accommodate a Z-axis sensing coil (the sensing coil is not shown in FIGS. **15**A-**15**B), for sensing an electromagnetic field in the Z axis, where the Z axis may coincide with the longitudinal axis of the in-vivo device.

[0119] MFS section **1374** and PCB section **1372** make up, or form, SCA **1530**. Trailing PCB section **1370**, which is structurally and functionally connected to MFS section **1374** and to PCB section **1372** (via PCB section **1379** and PCB section **1378**, respectively), may be regarded as a structural and functional PCB junction, or an intersection hub, that interconnects primary PCB section **1520** and SCA **1530**.

[0120] In accordance with FIGS. **15**A-**15**B, there is provided an embodiment in which a foldable multilayered imaging and sensing printed circuit board (MISP) for an in-vivo device may include a primary printed circuit board (PCB) section (e.g., primary PCB section **1520**), the primary PCB section may include a first/leading PCB section (e.g., leading PCB section **1330**), a second/trailing PCB section (e.g., trailing PCB section **1370**), and one or more primary PCB sections that are disposed in-between the first/leading PCB section and the second/trailing PCB section (e.g., primary PCB sections **1340**, **1350**, and **1360**). The first/leading PCB section, second/trailing PCB section and the one or more primary PCB sections may be interconnected (e.g., via PCB sections **1346**, **1346**, **1356**, and **1364**). The MSIP may further include a sensing coils assembly (SCA) that may include a magnetic field sensing (MFS) section (e.g., MSF section **1374**) and a PCB section (e.g., second PCB section **1372**), the MFS section and the second PCB section may be connected via, or to, the (junction-like) second/trailing PCB section. The MSF section may include sensing coils for sensing electromagnetic fields in two axes of the X-Y-Z coordinates system (e.g., X and Y axes), and the PCB section/portion may include a sensing coil for sensing an electromagnetic field in a third axis (e.g., Z axis). The sensing coil that senses the electromagnetic field in the third axis and the PCB portion on which it is mounted or formed may be regarded as part of the MSF section.

[0121] The articles "a" and "an" are used herein to refer to one or to more than one (i.e., to at least one) of the grammatical object of the article, depending on the context. By way of example, depending on the context, "an element" can mean one element or more than one element. The term "including" is used herein to mean, and is used interchangeably with, the phrase "including but not limited to". The terms "or" and "and" are used herein to mean, and are used interchangeably with, the term "and/or," unless context clearly indicates otherwise. The term "such as" is used herein to mean, and is used interchangeably, with the phrase "such as but not limited to".

[0122] Having thus described exemplary embodiments of the invention, it will be apparent to those skilled in the art that modifications of the disclosed embodiments will be within the scope of the invention. Alternative embodiments may, accordingly, include more modules, fewer modules and/or functionally equivalent modules. The present disclosure is relevant to various types of in-vivo devices (e.g., in-vivo devices with one or more imagers, in-vivo devices with no imagers at all, etc.), and to various types of electromagnetic field sensors (e.g., various types of magnetometers). Hence the scope of the claims that follow is not limited by the disclosure herein.

1. An electromagnetically maneuverable in-vivo device comprising:

a magnetic steering unit maneuverable by an external electromagnetic field, said magnetic steering unit comprising,

a permanent magnets assembly for interacting with the electromagnetic field to produce a propelling force and a rotational force for moving and rotating the in-vivo device, said permanent magnets assembly comprising at least one permanent magnet, and

a magnet carrying assembly to accommodate the at least one permanent magnet, said magnet carrying assembly capable of interacting with an electromagnetic field to generate eddy currents to produce a repelling force; and

a sensing coil assembly for sensing electromagnetic fields in order to facilitate sensing of a location, orientation and angular position of the in-vivo device, said sensing coil assembly comprising electromagnetic field sensors disposed on one or more printed circuit board sections, wherein at least one of the one or more printed circuit board sections is foldable to make the electromagnetic field sensors mutually perpendicular.

2. The in-vivo device as in claim **1**, wherein the permanent magnets assembly and the sensing coil assembly partly or fully structurally and concentrically overlap.

3. The in-vivo device as in claim **1**, wherein the permanent magnets assembly and the sensing coil assembly do not structurally and concentrically overlap.

4. The in-vivo device as in claim **1**, further comprising a foldable multilayered imaging and sensing printed circuit board, the multilayered imaging and sensing printed circuit board comprising:

a primary printed circuit board branch;

one or more secondary printed circuit board branches intersecting the primary printed circuit board; and

one or more tertiary printed circuit board branches intersecting the secondary printed circuit board,

wherein the primary printed circuit board branch, at least one of the one or more secondary printed circuit board branches, and at least one of the tertiary printed circuit board branches include an electrical circuit, and wherein one or more printed circuit board branches selected from the group consisting of the one or more secondary printed circuit board branches and the one or more tertiary printed circuit board branches include the sensing coils assembly, the sensing coils assembly functionally coupled to the electrical circuit.

5. The in-vivo device as in claim **4**, wherein portions of the multilayered imaging and sensing printed circuit board include four printed circuit board layers.

6. The in-vivo device as in claim **4**, wherein a portion of a tertiary printed circuit board branch includes X-Y sensing coils for respectively sensing electromagnetic field components in the X-direction and Y-direction, and wherein another portion of the tertiary printed circuit board branch includes a Z sensing coil for sensing an electromagnetic field component in the Z-direction.

7. The in-vivo device as in claim **4**, wherein the electrical circuitry comprises an imaging circuitry.

8. The in-vivo device as in claim **4**, wherein the multilayered imaging and sensing printed circuit board includes rigid portions and flexible portions.

9. The in-vivo device as in claim **4**, wherein the multilayered imaging and sensing printed circuit board is fully flexible.

10. The in-vivo device as in claim **4**, wherein the primary printed circuit board branch and the secondary printed circuit board branches are partly rigid and partly flexible.

11. The in-vivo device as in claim **10**, wherein the primary printed circuit board branch and the secondary printed circuit board branches are foldable such that portions of the primary printed circuit board branch and portions of the secondary printed circuit board branches are parallel and other portions thereof connect the parallel portions.

12. The in-vivo device as in claim **4**, wherein a tertiary printed circuit board branch is fully flexible.

13. The in-vivo device as in claim **12**, wherein the tertiary printed circuit board branch is cylindrically foldable.

14. The in-vivo device as in claim **4**, wherein the sensing coils assembly comprises one or more electromagnetic field sensors.

15. The in-vivo device as in claim **1**, further comprising a foldable multilayered imaging and sensing printed circuit board comprising:

a primary printed circuit board section, said primary printed circuit board section comprising a first printed circuit board section, a second printed circuit board section, and one or more printed circuit board sections that are disposed in-between the first printed circuit board section and the second printed circuit board section, the first printed circuit board section, second printed circuit board section, and the one or more printed circuit board sections being interconnected via flexible printed circuit board sections; and

the sensing coils assembly, said sensing coils assembly comprising a magnetic field sensing section and a printed circuit board section, the magnetic field sensing section and the printed circuit board section being connected via or to said second printed circuit board section,

wherein the magnetic field sensing section includes sensing coils for sensing electromagnetic fields in two axes, and the printed circuit board section includes a sensing coil for sensing an electromagnetic field in a third axis.

16. An assembly for an in-vivo device, comprising:

an electrically conductive tubular object for inducing eddy current, the tubular object including a slit for reducing parasitic currents;

two or more electrically conductive annular discs for augmenting the induced eddy current, said conductive annular discs being disposed on the tubular object and forming one or more circumferential open annular channels around the conductive tubular object;

a set of one or more annular permanent magnets held in the one or more annular channels; and

a set of one or more conductive discs for further augmenting the induced eddy current, a first conductive disc being mounted on a first side of the tubular object and a second conductive disc being mounted on a second side of the tubular object opposite the first side.

17. The assembly as in claim **16**, further comprising one or more batteries contained in a chamber formed by the first conductive disc, the second conductive disc, and a portion of the inner surface of the tubular object.

18. An in-vivo device comprising a multilayered imaging and sensing printed circuit board according to claim **4** or claim **15**, and an assembly according to claim **16**.

19. The in-vivo device as in claim **18**, wherein the assembly is contained in or circumscribed by the multilayered imaging and sensing printed circuit board.

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