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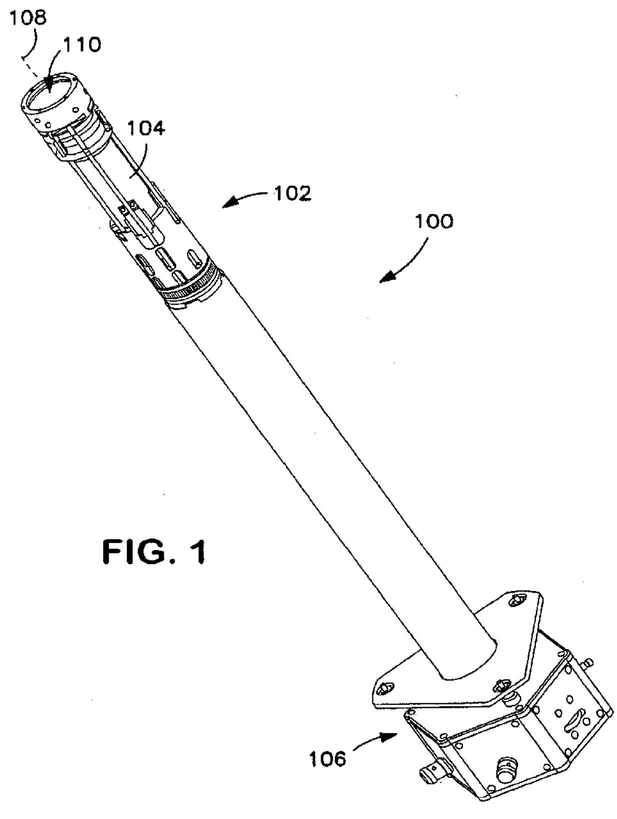

FIG. 1

(57) Abstract: A coil assembly for transmitting or receiving radio frequency signals includes a coil, a capacitive tuning ring, a first capacitive shield, and a second capacitive shield. The coil includes axial conductors extending between first and second end regions and arranged about a longitudinal axis. The tuning ring is axially movable wherein an amount by which the tuning ring overlaps the plurality of axial conductors is adjustable. The first capacitive shield is axially movable relative to a first group of axial conductors wherein an amount by which the first capacitive shield overlaps the first group is adjustable. The second capacitive shield, offset ninety degrees from the first capacitive shield, is axially movable relative to a second group of axial conductors wherein an amount by which the second capacitive shield overlaps the second group is adjustable. The capacitive shields enable the coil to be quadrature balanced.

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DIFFERENTIAL TUNING OF QUADRATURE MODES OF A MAGNETIC RESONANCE COIL

PRIORITY CLAIM

[0001] This application claims priority from provisional application number 61/066,140, filed January 25, 2008.

FIELD OF THE INVENTION

[0002] The present invention relates generally to coils utilized for radio-frequency signal transmission and reception, particularly coils operated in quadrature. More particularly, the invention relates to frequency-tuning and quadrature-balancing such coils. Such coils may be utilized, for example, in nuclear magnetic resonance (NMR) techniques.

BACKGROUND OF THE INVENTION

[0003] Coils of various designs have been utilized to transmit (send) and receive wireless signals, particularly radio-frequency (RF) signals in a wide variety of contexts, including nuclear magnetic resonance (NMR) spectrometry and magnetic resonance imaging (MRI). An NMR spectrometer or MRI apparatus typically includes RF transmitting/receiving electronics, a sample probe, and a source of a strong magnetic field in which the sample probe is immersed such as a superconducting magnet. The sample probe contains a liquid or solid sample or a biological (human or animal) subject and one or more RF coils that serve as the electromagnetic coupling between the RF electronics and the sample. The RF electronics are operated to irradiate the sample with RF energy and receive RF signals emitted from the sample in response to the RF input. The response signals are utilized to extract spectrometric or imaging information regarding the sample. The same coil may be employed to transmit and receive the RF energy, particularly in applications where RF input (excitation) and output (signal detection) occur at different times. Typically, the coil is cylindrical and surrounds the sample.

[0004] One popular coil utilized in NMR-related applications is commonly known as a birdcage coil. The typical birdcage coil consists of a cylindrical arrangement of 4, 8, 16 or 32 axially-oriented, parallel conductive legs (or fingers, rungs, etc.) evenly distributed about a central axis. The multiple of four in the number of legs facilitates quadrature operation. The legs typically extend between two conductive end loops (or rings). Increasing the number (and thus density) of the legs increases the homogeneity of the magnetic B_1 field applied by the coil. As the B_1 field oscillates at a desired resonant RF frequency, the current flowing through the legs approximates a sinusoidal-weighted distribution as one moves along polar angle positions from 0 to 360 degrees relative to the central axis of the cylindrical coil structure. A variation of the birdcage coil is the Millipede™ coil commercially available from Varian, Inc., Palo Alto, California. The Millipede™ coil includes a much larger number of legs (typically 200 or more). The increased density of legs in the Millipede™ coil increases the RF magnetic homogeneity exhibited by the coil.

[0005] The birdcage or Millipede™ coil can be driven linearly by coupling the RF transmit/receive electronics to a single leg of the coil via a single coaxial cable. To double the RF power efficiency during signal transmission and reduce the signal-to-noise ratio by a factor of $\sqrt{2}$ (about 1.41) during signal reception, the coil can be driven in quadrature by coupling the RF transmit/receive electronics to two legs of the coil located ninety degrees apart via two coaxial cables. In this case, the signals corresponding to the two orthogonal quadrature modes are ninety degrees out of phase relative to each other. The two detection signals are combined in a combiner circuit of the RF electronics and processed in a known manner.

[0006] To operate on nuclear magnetic resonant phenomena, the coil must be tuned to a resonant frequency dependent on the static magnetic B_0 field being applied and the nuclei being analyzed. The tuning must be accomplished in a manner that maintains the electrical symmetry of the coil, the homogeneity of the RF fields produced by the coil, and an acceptable level of signal-to-noise ratio. Moreover, once the coil has been tuned to a desired frequency, the subsequent loading of the sample to be analyzed in the core surrounded by the coil requires that the coil be retuned to the desired frequency because the resident sample causes detuning, a shift in the resonance frequency of the RF coil as seen by the operator. When operating in quadrature, both modes must be tuned to the same resonant frequency. Asymmetry in the sample loaded into the observation space within the coil, as well as asymmetry in the coil itself due to the limitations of manufacturing technology, cause quadrature imbalance and attendant problems such as lowered signal-to-noise ratio.

[0007] To effect the required tuning, approaches entailing the use of variable capacitors and discrete capacitors have been incorporated into birdcage-type coils that enable capacitances to be adjusted. In the case of Millipede™ coils, the capacitances defining the resonant frequency of the coil structure may be formed by overlapping conductive surfaces on either side of a dielectric substrate utilized as a coil former, thus producing an RF-transmitting structure having distributed capacitances. In one design, a tune ring consisting of a conductive element supported on a dielectric substrate is located at one end of a birdcage coil and is moved over the legs of the coil to vary capacitance and thereby adjust frequency. A variation of this design adds a second movable tune ring at the other axial end of the coil. The tune ring or rings enable the adjustment of capacitance of all legs, and thus the frequency of the coil, in a global manner. The effect of sample loading on the tuning of the coil is often on the order of a few percent, especially at frequencies of 400 MHz and up. The tuning range must be wide enough to enable the coil to be retuned to the desired frequency irrespective of the level of sample loading. Designs that employ global tuning mechanisms have generally resulted in relatively narrow tuning ranges. Mechanical tolerances and small asymmetries in the coil structure will lead to quadrature imbalances over the tuning range of the coil if larger variations in capacitance are called for to obtain the large tuning range. Accordingly, a coil, and particularly one with a global tuning mechanism, should have a mechanism to readjust the quadrature balance.

[0008] Accordingly, there is an acknowledged ongoing need for improvements in RF coil design, particularly in the design of coils operated in quadrature. In particular, there is a need for providing coils that can be tuned over a large frequency range while maintaining balanced quadrature modes.

SUMMARY OF THE INVENTION

[0009] To address the foregoing problems, in whole or in part, and/or other problems that may have been observed by persons skilled in the art, the present disclosure provides apparatus, devices, systems and/or methods relating to proportional valves, as described by way of example in implementations set forth below.

[0010] According to one implementation, a coil assembly is provided for transmitting or receiving radio frequency signals. The coil assembly includes a coil, a capacitive tuning ring, a first capacitive shield, and a second capacitive shield. The coil may include a first end region and a second end region disposed about a longitudinal axis of the coil. The first and second end regions are axially spaced from each other. The coil may further include a plurality of parallel axial conductors extending between the first end region and the second end region. The axial conductors are circumferentially spaced from each other about the longitudinal axis. The capacitive tuning ring is disposed about the longitudinal axis in overlapping relation to the axial conductors at the first end region. The tuning ring is axially movable relative to the coil wherein an amount by which the tuning ring overlaps the plurality of axial conductors is adjustable. The first capacitive shield is disposed in overlapping relation to a first group of the axial conductors at the second end region. The first capacitive shield is axially movable relative to the first group wherein an amount by which the first capacitive shield overlaps the first group is adjustable. The second capacitive shield is disposed in overlapping relation to a second group of the axial conductors at the second end region, and is circumferentially offset ninety degrees from the first capacitive shield relative to the longitudinal axis. The second capacitive shield is axially movable relative to the second group wherein an amount by which the second capacitive shield overlaps the second group is adjustable.

[0011] According to another implementation, a coil assembly includes an adjustment mechanism. The adjustment mechanism includes a linkage coupled to a first capacitive shield and a second capacitive shield. The linkage is configured to move the first capacitive shield and the second capacitive shield simultaneously in response to an actuating input to the linkage.

[0012] According to another implementation, a coil assembly includes an adjustment mechanism. The adjustment mechanism includes a linkage coupled to a first capacitive shield and a second capacitive shield. The linkage is configured to move the first capacitive shield and the second capacitive shield in opposite axial directions in response to an actuating input to the linkage.

[0013] According to another implementation, a method is provided for tuning the frequency at which a coil transmits or receives wireless signals. Such a coil may include a first end region, a second end region axially spaced from the first end region relative to a longitudinal axis of the coil, and a plurality of axial conductors circumferentially arranged about the longitudinal axis and extending between the first end region and the second end region. A capacitive tuning ring is moved axially relative to the longitudinal axis to adjust an amount by which the tuning ring overlaps the axial conductors at the first end region. A first capacitive shield is moved axially relative to the longitudinal axis in a first direction to adjust an amount by which the first capacitive shield overlaps a first group of the axial conductors. Simultaneously with moving the first capacitive shield, a second capacitive shield is moved axially relative to the longitudinal axis in a second direction opposite to the first direction to adjust an amount by which the second capacitive shield overlaps a second group of the axial conductors. The second group of axial conductors is positioned ninety degrees away from the first group of axial conductors relative to the longitudinal axis.

[0014] According to another implementation of a method for tuning the frequency at which a coil transmits or receives wireless signals, a first capacitive shield and a second capacitive shield are moved simultaneously.

[0015] According to another implementation of a method for tuning the frequency at which a coil transmits or receives wireless signals, a first capacitive shield is moved in a first axial direction and a second capacitive shield is moved in a second axial direction opposite to the first direction.

[0016] According to another implementation of a method for tuning the frequency at which a coil transmits or receives wireless signals, a first capacitive shield and a second capacitive shield are moved by actuating a single adjustment mechanism.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The invention can be better understood by referring to the following figures. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention. In the figures, like reference numerals designate corresponding parts throughout the different views.

[0018] Figure 1 is a perspective view of an example of a coil assembly according to one or more implementations taught in the present disclosure.

[0019] Figure 2 is an elevation view of another example of a coil assembly according to one or more implementations taught in the present disclosure.

[0020] Figure 3 is a top view of the coil assembly of Figure 2.

[0021] Figure 4 is a bottom view of the coil assembly of Figure 2.

[0022] Figure 5 is a cross-sectional view of an example of an arrangement of conductive and dielectric elements that may be utilized to adjust capacitance.

[0023] Figure 6 is a perspective view of another example of a coil assembly according to one or more implementations taught in the present disclosure.

[0024] Figure 7 is another perspective view of the coil assembly of Figure 6, rotated 180 degrees about a cylindrical axis.

[0025] Figure 8 is another perspective view of the coil assembly of Figure 6, rotated 90 degrees about a cylindrical axis.

[0026] Figure 9 is an elevation view of a portion of the coil assembly of Figure 6, illustrating the adjustment of capacitive shields according to an implementation taught in the present disclosure.

[0027] Figure 10 is another elevation view of the portion of the coil assembly illustrated in Figure 9.

[0028] Figure 11 is a perspective view of an example of a section of a coil assembly that includes user controls and adjustment mechanisms, according to an implementation taught in the present disclosure.

[0029] Figure 12 is a perspective view of an example of a mechanism that adjusts a tuning ring, according to an implementation taught in the present disclosure.

[0030] Figure 13 is a plan view of an example of a mechanism that adjusts capacitive shields, according to an implementation taught in the present disclosure.

DETAILED DESCRIPTION OF THE INVENTION

[0031] The subject matter disclosed herein generally relates to systems, apparatus, devices, instruments, processes and methods related to coils utilized for RF signal transmission and reception, such as for example may be utilized in the analysis of samples according to NMR techniques. Examples of implementations relating to the invention are described in more detail below with reference to Figures 1 – 13. These examples are provided in the context of NMR technology, but it will be recognized that the broad aspects of the invention may be applicable to other types of technologies entailing RF signal transmission and reception.

[0032] Figure 1 is a perspective view of an example of a coil assembly **100**. The coil assembly **100** may include a first section **102** supporting a coil structure **104** and a second section **106** containing other electrical and mechanical components. The first section **102** is generally arranged about a central longitudinal axis **108** and encloses a bore **110** into which a sample to be analyzed is introduced. The bore **110** may be continued through the second section **106**.

[0033] Figures 2-4 are simplified schematic views of an example of a coil assembly **200** and associated coil **204.** The structure of the coil **204** is generally arranged about a central longitudinal axis **208** and encloses an interior space into which a sample to be analyzed is introduced. The coil **204** generally includes a first end region and a second end region axially spaced from each other, and axial conductors extending between the first and second end regions. In the illustrated example, the coil **204** includes a first annular conductor **212** and a second annular conductor **214** disposed about the longitudinal axis **208** and axially spaced from each other. A plurality of axial conductors **216** is disposed in parallel with the longitudinal axis at a radial distance therefrom. The axial conductors **216** are circumferentially spaced from each other relative to the longitudinal axis **208**. In the illustrated example, the resulting geometry of the coil **204** is cylindrical. It will be understood, however, that the geometry of the coil **204** may deviate somewhat from a perfect cylinder or may have a different hollow form such as an elliptical shape. The axial conductors **216** terminate at respective first axial ends **218** and opposing second axial ends **220**. The first axial ends **218** may be positioned in overlapping relation with the first annular conductor **212** at a radial distance from the first annular conductor **212** relative to the longitudinal axis **208**. The second axial ends **220** may be positioned in overlapping relation with the second annular conductor **214** at a radial distance from the annular conductor **214** relative to the longitudinal axis **208**. The coil **204** may be characterized as a birdcage-type coil. In some implementations the coil includes a large number of axial conductors **216** (e.g., about 200 or greater) such as in the case of the above-mentioned Millipede™ coil.

[0034] The coil assembly **200** in which the coil **204** is provided may include a capacitive tuning ring **222**. The tuning ring **222** is disposed about the longitudinal axis **208** in overlapping relation with the first axial ends **218** of the axial conductor and with the first annular conductor **212**, at a radial distance from these components relative to the longitudinal axis **208**. In Figure 2, the tuning ring **222** is schematically depicted by two lines to illustrate its position relative to the other components. In practice, the tuning ring **222** may have a circumferentially complete annular structure such that the tuning ring **222** overlaps the first axial ends **218** of all axial conductors **216** (see Figure 3). The coil assembly **200** includes means for enabling the axial position of the tuning ring **222** to be adjusted relative to the fixed-position coil **204**, i.e., relative to the axial positions of the first annular conductor **212** and the axial conductors **216**. The axial mobility of the tuning ring **222** is depicted by an arrow **225**. The axial adjustability of the tuning ring **222** enables the amount of overlap between the tuning ring **222** and the first annular conductor **212** and the first axial ends **218** to be adjusted. As appreciated by persons skilled in the art, the adjustability enables the capacitive coupling between the first annular conductor **212** and the axial conductors **216** to be adjusted. Accordingly, the tuning ring **222** may be utilized for "rough" tuning the coil **204** over a large frequency range. The coil assembly **200** may be configured to limit adjustment of the tuning ring **222** such that the tuning ring **222** cannot extend into the field-of-view (FOV) presented by the coil structure and thus does not cause distortion of the images derived from RF signals acquired from the sample under observation. The FOV may generally be defined as the space occupied by the coil **204** axially extending between the first annular conductor **212** and the second annular conductor **214**, as depicted by boundary lines **226** and **228**.

[0035] As best shown in Figure 4, the coil assembly **200** may also include two capacitive shields **232** and **234.** As evident from Figure 2, each capacitive shield **232** and **234** is disposed about the longitudinal axis **208** in overlapping relation with a group of adjacent second axial ends **220** of the axial conductors **216** and with the second annular conductor **214**, at a radial distance from these components relative to the longitudinal axis **208**. Relative to the longitudinal axis **208**, the two capacitive shields **232** and **234** are offset ninety degrees from each other (Figure 4) and thus overlap with two different groups of adjacent second axial ends **220**. The coil assembly **200** includes means for enabling the axial positions of the capacitive shields **232** and **234** to be adjusted relative to the axial positions of the second annular conductor **214** and the respective groups of axial conductors **216**. The axial mobility of the capacitive shields **232** and **234** is depicted by an arrow **235** in Figure 2. The axial adjustability of the capacitive shields **232** and **234** enables the amount of overlap between the capacitive shields **232** and **234** and the second annular conductor **214** and respective groups of axial conductors **216** to be adjusted. This adjustability enables the capacitive coupling between the second annular conductor **214** and the axial conductors **216** to be adjusted. In comparison to the tuning ring **222**, the two ninety-degree offset capacitive shields **232** and **234** are small arcs (compare Figures 3 and 4). Thus, the axial adjustment of one capacitive shield **232** or **234** will affect the frequency tuning of one quadrature mode only. By this configuration, the capacitive shields **232** and **234** may be utilized as a quadrature balance "fine" tuning mechanism that restores the quadrature balance between the two quadrature modes caused by asymmetry in the coil **204**, the sample, and/or the rough-tune tuning ring **222**. Like the tuning ring **222**, the coil assembly **200** may be configured to limit adjustment of the capacitive shields **232** and **234** such that the capacitive shields **232** and **234** cannot extend into the field-of-view (FOV) presented by the coil structure. As described in more detail below, the coil assembly **200** may be configured to adjust the capacitive shields **232** and **234** in a differential fashion.

[0036] Figure 3 schematically illustrates a top view of the coil assembly **200.** From the perspective of Figure 3, the first annular conductor **212** of the coil is visible. The tuning ring **222** surrounds the first annular conductor **212** and the proximate ends of the axial conductors (not shown) of the coil, thereby enabling simultaneous rough tuning of both quadrature channels.

[0037] Figure 4 schematically illustrates a bottom view of the coil assembly **200.** From the perspective of Figure 4, the second annular conductor **214** of the coil is visible. The two capacitive shields **232** and **234** are located ninety degrees from each other in accordance with a quadrature mode of operation of the coil. The two capacitive shields **232** and **234** overlap the second annular conductor **214** and two different groups of axial conductors (not shown) as noted above. Figure 4 also illustrates the positions of two impedance-matching circuits **436** and **438** corresponding to the two quadrature channels. In practice, two RF transmission lines (e.g., 50-Ω coaxial cables) are coupled to the coil at the respective matching circuits **436** and **438**. The two matching circuits **436** and **438** communicate with the coil at locations 180 degrees from the two capacitive shields **432** and **434**, respectively. The matching circuits **436** and **438** may include variable capacitors and other components useful for impedance matching as appreciated by persons skilled in the art. In one example, the variable capacitors of the matching circuits **436** and **438** may be adjustable by axially moving the capacitors or a component of the capacitors.

[0038] Figure 5 is a cross-sectional view of an example of an arrangement of capacitive elements that may be realized in a coil assembly. Specifically, Figure 5 illustrates the respective radial positions of a first annular conductor **512** of a coil, an axial conductor **516** of the coil, and a tuning ring **522**. By way of example, the annular conductor **512** and the axial conductors **516** may be fabricated by known fabrication techniques on a coil former **540** such as a flexible circuit board composed of a dielectric material. The axially movable tuning ring **522** may similarly include a conductive portion **542** supported by a dielectric substrate **544**. The conductive portions of the annular conductor **512**, the axial conductors **516** and the tuning ring **522** may be composed of, for example, copper, gold, silver, platinum, or any other suitable electrically conductive material. For reference purposes, Figure 5 illustrates an upper boundary **526** of the FOV of the resulting coil. Figure 5 is also analogously representative of the respective radial positions of a second annular conductor, axial conductors, and capacitive shields located at the opposite end of the coil.

[0039] In the example illustrated in Figure 5, the axial conductors **516** are located radially outward of the annular conductors **512**. That is, the axial conductors **516** are located at a greater radial distance from the longitudinal axis of the coil than the annular conductors **512**.

The tuning ring **522** in turn is located radially outward of the axial conductors **516**. The relative radial positions of these components may be changed in other implementations.

[0040] Figure 6 is a perspective view of another example of a coil assembly **600**. The coil assembly **600** may include means for moving or guiding the axial movement of two capacitive shields **632** and **634** relative to a coil **604**. In the illustrated example, the coil assembly **600** includes two elongate members **646** and **648** located ninety degrees apart that respectively support the axial movement of the two capacitive shields **632** and **634**. As an example, the elongate members **646** and **648** may be threaded rods that are free to rotate about their respective axes but are axially fixed in their positions illustrated in Figure 6. The capacitive shields **632** and **634** may include carriages **652** and **654** supporting the conductive portions of the capacitive shields **632** and **634**. The carriages **652** and **654** may include threaded portions that engage the threaded rods **646** and **648**. By this configuration, rotation of the rods **646** and **648** actuates the movement of the capacitive shields **632** and **634** axially up and down relative to the coil **604**. To maintain proper alignment of the capacitive shields **632** and **634**, the carriages **652** and **654** may include one or more tongues **656** extending in parallel with the axial direction of movement. The tongues **656** are guided in corresponding grooves or recesses **658** formed in a portion of the coil assembly **600**. The coil assembly **600** may also include means for limiting the axial movement of the capacitive shields **632** and **634**, such as stop mechanisms. In the illustrated example, the coil assembly **600** includes stop members **666** and **668** linked to the respective capacitive shields **632** and **634**. The stop members **666** and **668** move axially within respective openings (e.g., slots) **667** and **669**. Contact between the stop members **666** and **668** and upper and lower edges of their respective slots **667** and **669** provides upper and lower limits to the axial excursions of the capacitive shields **632** and **634**.

[0041] As also illustrated in Figure 6, the coil assembly **600** may include one or more other threaded rods **672** and **674** or other types of elongate members that support the axial adjustment of a tuning ring **622**. The tuning ring **622** may likewise be coupled to the threaded rods **672** and **674** such that rotation of the threaded rods **672** and **674** drives the tuning ring **622** axially upward or downward. When two such rods **672** and **674** are provided, they may be located 180 degrees apart as illustrated in the example. At the present time, it has been found that the illustrated arrangement of two rods **672** and **674** facilitates the adjustment of the tuning ring **622** in a precise manner that maintains the proper alignment of the tuning ring **622** relative to other components of the coil **604** and associated coil assembly **600**.

[0042] Figure 7 is another perspective view of the coil assembly **600** illustrated in Figure 6, rotated 180 degrees about the longitudinal axis. Two matching circuits **636** and **638** are located ninety degrees apart and 180 degrees away from the respective capacitive shields **632** and **634** (Figure 6). The matching circuits **736** and **738** include respective variable capacitors. These capacitors (or components thereof) may be axially adjustable. Stop members **776** and **778** moving in corresponding slots may be provided to limit the axial movements of the variable capacitors, respectively. Figure 7 also illustrates two transmission lines **782** and **784** respectively coupled to the matching circuits **736** and **738**.

[0043] Figure 8 is another perspective view of the coil assembly **600** illustrated in Figure 6, rotated 90 degrees about the longitudinal axis such that one capacitive shield **632** and one matching circuit **738** are visible. One of the threaded rods **672** supporting the axial adjustment of the tuning ring **622** is also visible. A stop member **886** moving in a slot may be provided to limit the axial movement of the tuning ring **622**. Another stop member and corresponding slot may also be provided to limit the axial movement of the tuning ring **622** from the other side.

[0044] Figures 9 and 10 are perspective views of the section of the coil assembly **600** illustrated in Figure 6 that includes the two capacitive shields **632** and **634**. According to an implementation of the present disclosure, the capacitive shields **632** and **634** may be driven in a differential fashion by which a single fine-tuning adjustment made by a user will cause the capacitive shields **632** and **634** to move relative to each other in a manner effective to restore quadrature balance. To this end, the coil assembly **600** is configured such that making an adjustment will actuate one capacitive shield **632** or **634** to move up while simultaneously actuating the other capacitive shield **634** or **632** to move down. Consequently, the frequency of one quadrature mode is increased while the frequency of the orthogonal mode is decreased. The single adjustment made by the user may be realized by providing a single input device, such as a knob, dial, wheel or lever, etc., and associated mechanical linkages between the single input device and the threaded rods **646** and **648** on which the capacitive shields **632** and **634** respectively travel. Thus, in Figure 9 for example, moving (e.g., sliding, turning, rotating, etc.) the input device in one direction moves the first capacitive shield **632** down and simultaneously moves the second capacitive shield **634** up, as indicated by respective arrows **935** and **937**. Likewise in Figure 10, moving the input device in the opposite direction moves the first capacitive shield **632** up and simultaneously moves the second capacitive shield **634** down, as indicated by respective arrows **1035** and **1037**.

[0045] In other implementations, the coil assembly **600** may be configured to enable each capacitive shield **632** and **634** to be adjusted separately and independently of the other. Such a configuration, however, would require the user to make two adjustments that must be precisely coordinated to correctly balance the coil **604**. A properly configured arrangement as described above and illustrated in Figures 9 and 10 eliminates the need for making independent adjustments to the two capacitive shields **632** and **634**.

[0046] Figure 11 is a bottom perspective view of an example of a section **1106** of a coil assembly that may be included to provide user controls and adjustment mechanisms utilized to effect the adjustment of a tuning ring, capacitive shields, and match circuits as described above. The adjustment mechanisms may include suitable linkages (gears, etc.) to these adjustable components. The linkages may be actuated by any suitable input means, such as user-actuated inputs (knobs, wheels, levers or the like) or automated devices (solenoids, etc.). In the illustrated example an adjustment knob **1112** is coupled to a mechanism **1114** for adjusting the tuning ring, an adjustment wheel **1116** is coupled to a mechanism **1118** for adjusting the capacitive shields in a differential fashion, an adjustment knob **1122** is coupled to a mechanism **1124** for adjusting the first matching circuit associated with the first quadrature channel, and an adjustment knob **1126** is coupled to a mechanism **1128** for adjusting the second matching circuit associated with the second, perpendicular quadrature channel. The adjustment mechanisms **1114**, **1118**, **1124**, **1128** are coaxially situated about a central bore **1110** of the coil assembly in which a sample to be imaged is introduced. Figure 11 also illustrates a fitting **1130** utilized for gas purging, and feed-throughs **1132** and **1134** for routing coaxial cables **1182** and **1184** to appropriate connection points on the coil for quadrature operation.

[0047] Figure 12 illustrates an example of the mechanism **1114** for adjusting the tuning ring. The adjustment mechanism **1114** may be housed in a section of the coil assembly such as illustrated in Figure 11. In the illustrated example, the adjustment mechanism **1114** generally includes a gear train that couples the adjustment knob **1112** (see, e.g., Figure 11) with a pair of threaded rods. The gear train is configured such that rotation of the adjustment knob **1112** causes both threaded rods **1272** and **1274** to rotate in the same direction, thereby causing a tuning ring coupled to the threaded rods **1272** and **1274** to move axially up or down relative to a coil as described above. In the specific example, a shaft **1236** extending from the adjustment knob **1112** into this section of the coil assembly is coupled to a bevel gear **1238**. The bevel gear **1238** is coupled to another bevel gear **1240** mounted on a shaft **1242** oriented perpendicularly to the first shaft **1236**. Rotation of the shaft **1236** of the adjustment knob **1112** thus rotates the second shaft **1242**, which in turn rotates a spur gear **1244** attached to the second shaft **1242**. The spur gear **1244** is coupled to teeth formed on the inside of a ring **1246**. Rotation of the toothed ring **1246** simultaneously rotates respective pinion gears **1252** and **1254** mounted on the threaded rods **1272** and **1274**, thereby rotating the threaded rods **1272** and **1274**. One or more pairs of intermediate gears **1256** and **1258** mounted on fixed posts or shafts and coupled between the toothed ring **1246** and the pinion gears **1252** and **1254** may be provided.

[0048] Figure 13 illustrates an example of the mechanism **1118** for adjusting the capacitive shields in the above-described differential fashion. The adjustment mechanism **1118** may be housed in a section of the coil assembly such as illustrated in Figure 11. In the illustrated example, the adjustment mechanism **1118** generally includes a gear train that couples the adjustment wheel **1116** with a pair of threaded rods. The threaded rods may be coupled to the respective capacitive shields in any suitable manner, one example being through the use of carriages such as described above and illustrated in Figure 6. The gear train is configured such that rotation of the adjustment wheel **1116** causes the threaded rods to rotate in opposite directions, thereby causing one capacitive shield to move axially up and the other capacitive shield to move axially down at the same time, as described above. In the specific example, the adjustment wheel **1116** is coupled to a spur gear **1336**. The spur gear **1336** is coupled to a pinion gear **1352** mounted on one of the threaded rods and to an additional gear **1362** that is in turn coupled to a pinion gear **1354** mounted on the other threaded rod. The coupling between the spur gear **1336** of the adjustment wheel **1116** and the first pinion gear **1352** and additional gear **1362** may be effected through one or more intermediate gears **1364** as necessary. The additional gear **1362** coupled to the second pinion gear **1354** operates to rotate the second pinion gear **1354** in a direction opposite to the first pinion gear **1352**. Accordingly, rotation of the adjustment wheel **1116** in a given direction causes the first threaded rod to rotate in one direction and the second threaded rod to rotate simultaneously in the opposite direction.

[0049] From the foregoing description, it can be seen that implementations taught in the present disclosure enable a coil to be tuned over a large frequency range while maintaining balanced quadrature modes. Implementations of the coil assembly provide a capacitive tuning ring that rough-tunes the quadrature modes simultaneously albeit not always equally. Implementations of the coil assembly provide two small capacitive shields offset ninety degrees apart in correspondence with two quadrature modes. The capacitive shields enable fine tuning of both quadrature modes so that the quadrature balance may be adjusted, thereby retuning both modes to the same frequency.

[0050] Implementations taught in the present disclosure may be applicable to a wide variety of applications entailing the transmission and receiving of RF signals. One class of applications relates to magnetic resonance technology and the acquisition of spectroscopic and/or imaging data. Accordingly, the coils and associated coil assemblies taught herein may be utilized in nuclear magnetic resonance (NMR) and magnetic resonance imaging (MRI) applications.

[0051] In general, the term "communicate" (for example, a first component "communicates with" or "is in communication with" a second component) is used herein to indicate a structural, functional, mechanical, electrical, optical, magnetic, ionic or fluidic relationship between two or more components or elements. As such, the fact that one component is said to communicate with a second component is not intended to exclude the possibility that additional components may be present between, and/or operatively associated or engaged with, the first and second components.

[0052] It will be further understood that various aspects or details of the invention may be changed without departing from the scope of the invention. Furthermore, the foregoing description is for the purpose of illustration only, and not for the purpose of limitation—the invention being defined by the claims.

WHAT IS CLAIMED IS:

1. A coil assembly for transmitting or receiving radio frequency signals, the coil assembly comprising:

a coil including a first end region and a second end region disposed about a longitudinal axis of the coil and axially spaced from each other, and a plurality of parallel axial conductors extending between the first end region and the second end region and circumferentially spaced from each other about the longitudinal axis;

a capacitive tuning ring disposed about the longitudinal axis in overlapping relation to the plurality of axial conductors at the first end region, the tuning ring axially movable relative to the coil wherein an amount by which the tuning ring overlaps the plurality of axial conductors is adjustable;

a first capacitive shield disposed in overlapping relation to a first group of the axial conductors at the second end region, the first capacitive shield axially movable relative to the first group wherein an amount by which the first capacitive shield overlaps the first group is adjustable; and

a second capacitive shield disposed in overlapping relation to a second group of the axial conductors at the second end region and circumferentially offset ninety degrees from the first capacitive shield relative to the longitudinal axis, the second capacitive shield axially movable relative to the second group wherein an amount by which the second capacitive shield overlaps the second group is adjustable.

2. The coil assembly of claim 1, wherein:

the coil includes a first annular conductor disposed about the longitudinal axis at the first end region, and a second annular conductor disposed about the longitudinal axis at the second end region;

the plurality of axial conductors include respective first axial ends and second axial ends, each first axial end disposed in overlapping relation to the first annular conductor at a radial distance therefrom, and each second axial end disposed in overlapping relation to the second annular conductor at a radial distance therefrom;

the first capacitive shield is disposed in overlapping relation to the second annular conductor and the second axial ends of the first group of the axial conductors, and the first capacitive shield is axially movable relative to the second annular conductor and the first group wherein an amount by which the first capacitive shield overlaps the second annular conductor and the first group is adjustable; and

the second capacitive shield is disposed in overlapping relation to the second annular conductor and the second axial ends of the second group of the axial conductors, and the second capacitive shield is axially movable relative to the second annular conductor and the second group wherein an amount by which the first capacitive shield overlaps the second annular conductor and the second group is adjustable.

3. The coil assembly of claim 2, wherein the plurality of axial conductors is disposed at a greater radial distance from the longitudinal axis than the first annular conductor and the second annular conductor, the tuning ring is disposed at a greater radial distance from the longitudinal axis than the plurality of axial conductors, and the first capacitive shield and the second capacitive shield are disposed at a greater radial distance from the longitudinal axis than the plurality of axial conductors

4. The coil assembly of claim 1, further including an adjustment mechanism including a linkage coupled to the first capacitive shield and the second capacitive shield, the linkage configured to move the first capacitive shield and the second capacitive shield simultaneously in response to an actuating input to the linkage.

5. The coil assembly of claim 1, further including an adjustment mechanism including a linkage coupled to the first capacitive shield and the second capacitive shield, the linkage configured to move the first capacitive shield and the second capacitive shield in opposite axial directions in response to an actuating input to the linkage.

6. The coil assembly of claim 1, further including an adjustment mechanism coupled to the first capacitive shield and the second capacitive shield and configured to move the first capacitive shield and the second capacitive shield individually.

7. The coil assembly of claim 1, further including a first elongate member and a second elongate member disposed in parallel with the longitudinal axis, wherein the first capacitive shield is movably coupled to the first elongate member and the second capacitive shield is movably coupled to the second elongate member.

8. The coil assembly of claim 7, wherein the first elongate member includes a threaded portion, the first capacitive shield includes a threaded portion engaging the threaded portion of the first elongate member, the second elongate member includes a threaded portion, the second capacitive shield includes a threaded portion engaging the threaded portion of the second elongate member, and rotation of the first elongate member moves the first capacitive shield and rotation the second elongate member moves the second capacitive shield.

9. The coil assembly of claim 1, further including a first stop mechanism coupled between the first capacitive shield and the coil assembly and a second stop mechanism coupled between the second capacitive shield and the coil assembly.

10. The coil assembly of claim 9, wherein the first stop mechanism and the second stop mechanism respectively include a first stop member and a second stop member axially movable in respective openings formed in the coil assembly, and contact between each stop member and an edge of a respective opening defines a limit on axial movement of the corresponding capacitive shield in an axial direction.

11. The assembly of claim 10, wherein the first stop mechanism and the second stop mechanism are respectively positioned to prevent the first capacitive shield and the second capacitive shield from moving into a field of view of the coil, the field of view being defined as the space occupied by the coil between the first end region and the second end region.

12. The coil assembly of claim 1, further including a first impedance-matching circuit communicating with the coil at a point 180 degrees offset from the first capacitive shield relative to the longitudinal axis, and a second impedance-matching circuit communicating with the coil at a point 180 degrees offset from the second capacitive shield.

13. A method for tuning the frequency at which a coil transmits or receives wireless signals, the coil comprising a first end region, a second end region axially spaced from the first end region relative to a longitudinal axis of the coil, and a plurality of axial conductors circumferentially arranged about the longitudinal axis and extending between the first end region and the second end region, the method comprising:

moving a capacitive tuning ring axially relative to the longitudinal axis to adjust an amount by which the tuning ring overlaps the plurality of axial conductors at the first end region;

moving a first capacitive shield axially relative to the longitudinal axis to adjust an amount by which the first capacitive shield overlaps a first group of the axial conductors; and

moving a second capacitive shield axially relative to the longitudinal axis to adjust an amount by which the second capacitive shield overlaps a second group of the axial conductors, the second group being positioned ninety degrees away from the first group relative to the longitudinal axis.

14. The method of claim 13, further including operating the coil to transmit or receive two signals in phase quadrature.

15. The method of claim 13, wherein the first capacitive shield and the second capacitive shield are moved simultaneously.

16. The method of claim 13, wherein the first capacitive shield is moved in a first axial direction and the second capacitive shield is moved in a second axial direction opposite to the first direction.

17. The method of claim 13, wherein the first capacitive shield and the second capacitive shield are moved individually.

18. The method of claim 13, wherein moving the first capacitive shield and moving the second capacitive shield include actuating a single adjustment mechanism to move the first capacitive shield and the second capacitive shield simultaneously.

19. The method of claim 13, wherein moving the first capacitive shield and moving the second capacitive shield include actuating a single adjustment mechanism in a single direction to move the first capacitive shield in a first axial direction and move the second capacitive shield in a second axial direction.

20. The method of claim 13, further including limiting the movement of the first capacitive shield and the second capacitive shield wherein the first capacitive shield and the second capacitive shield cannot be moved into a field of view of the coil, the field of view being defined as the space occupied by the coil between the first end region and the second end region.

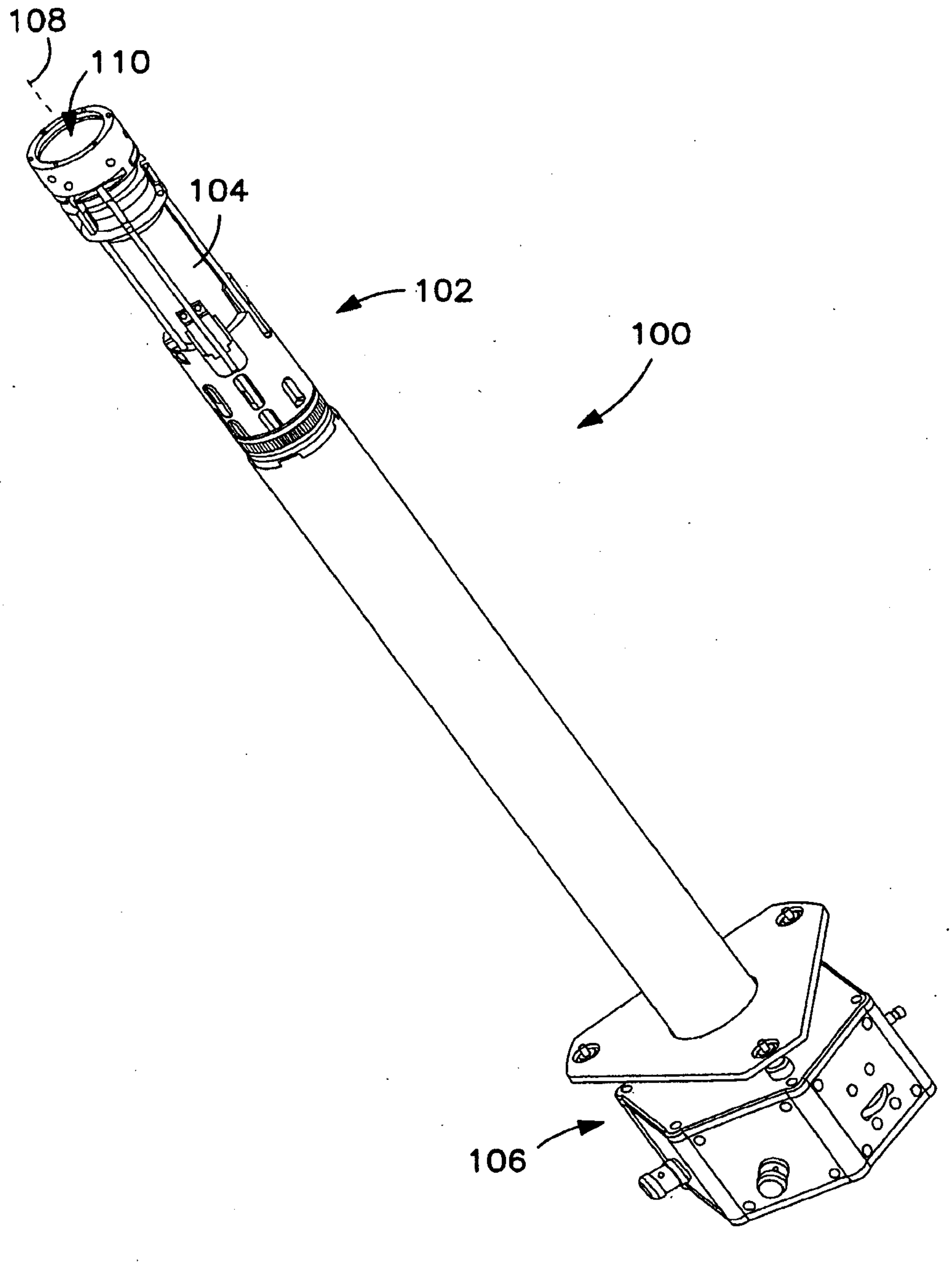

FIG. 1

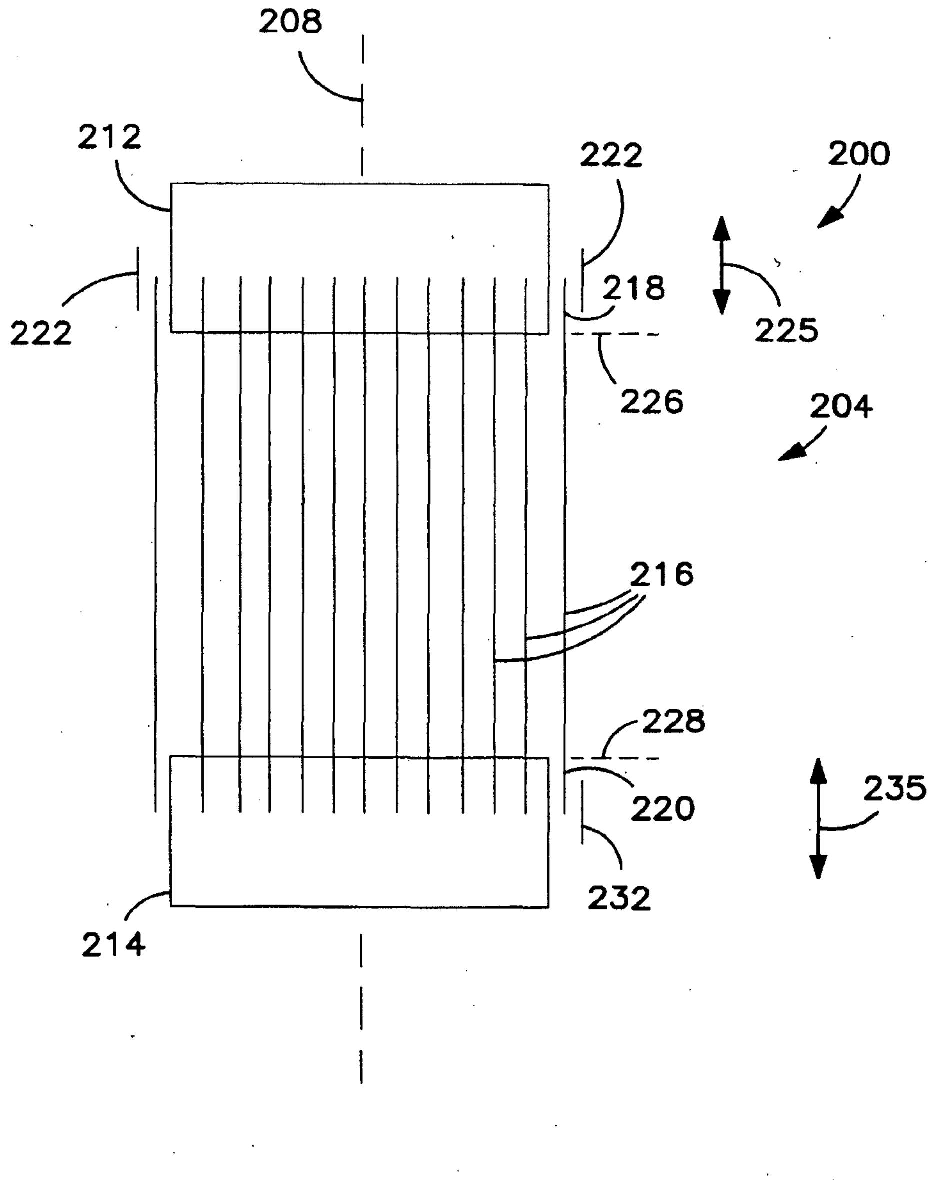

FIG. 2

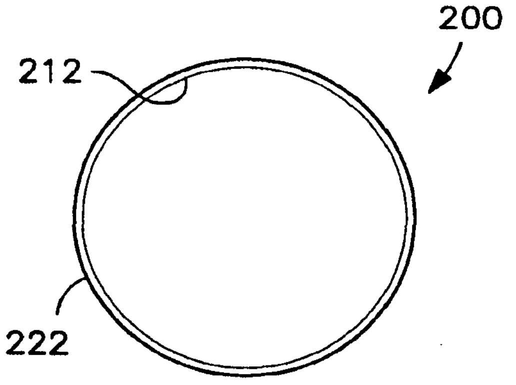

FIG. 3

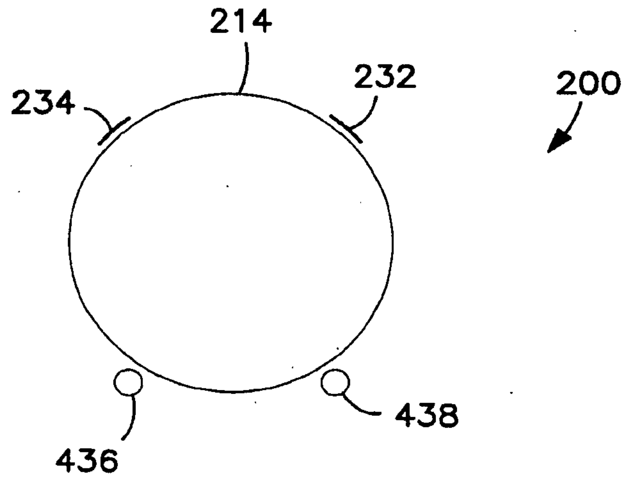

FIG. 4

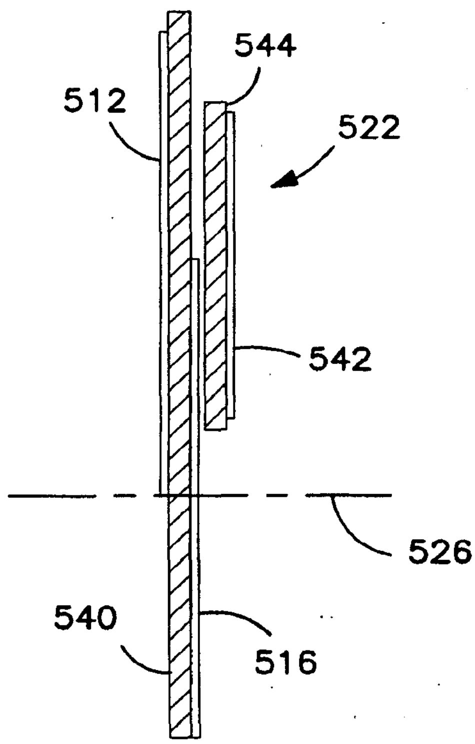

FIG. 5

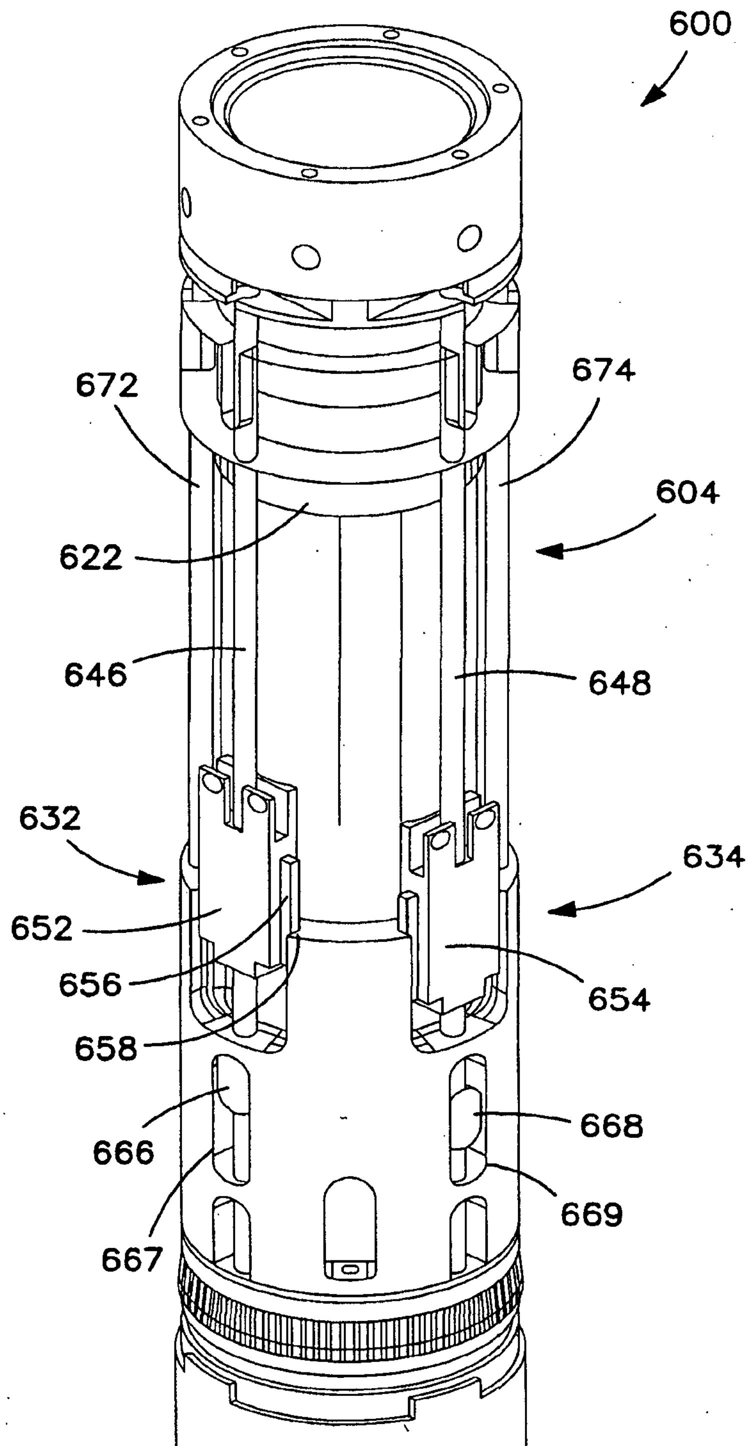
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FIG. 6

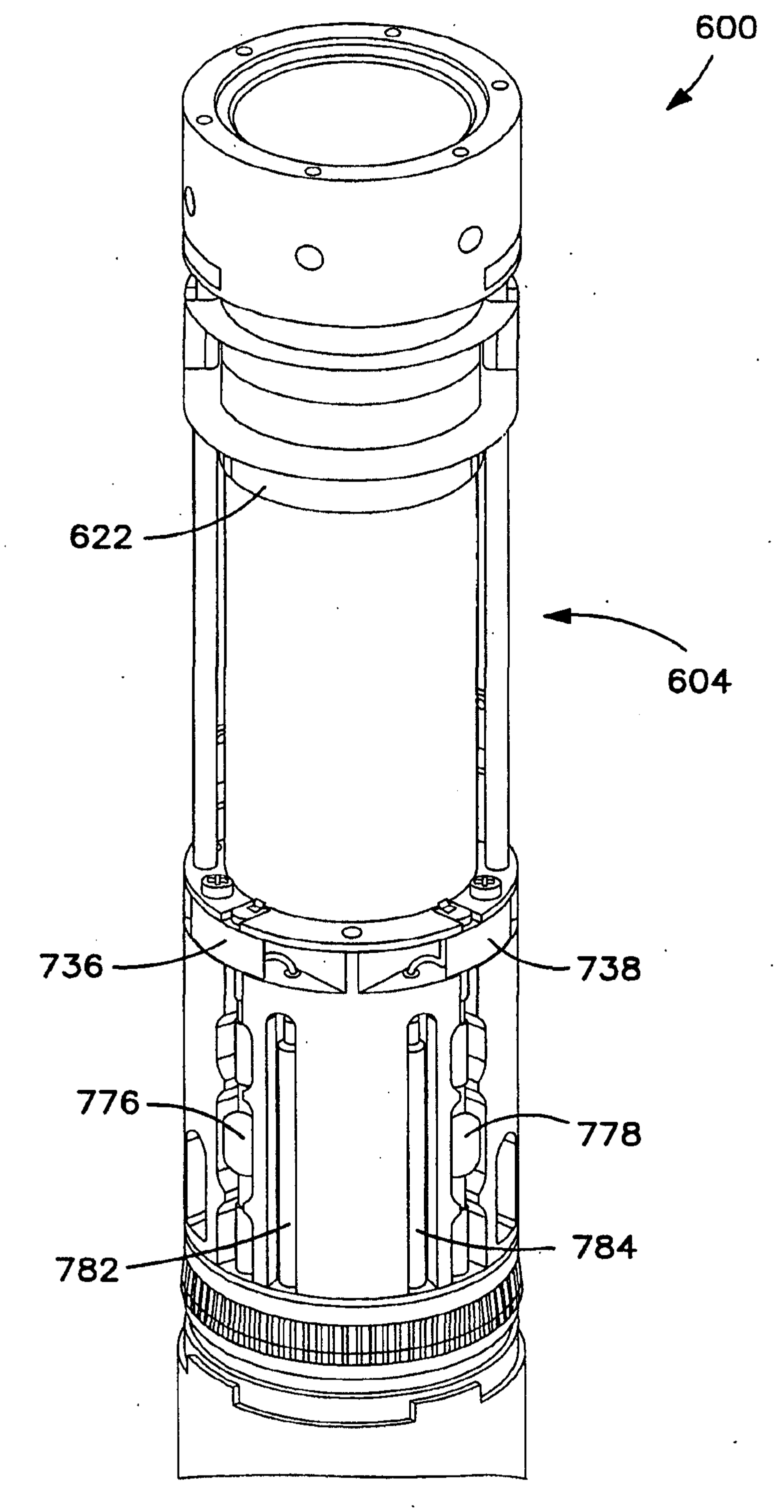

FIG. 7

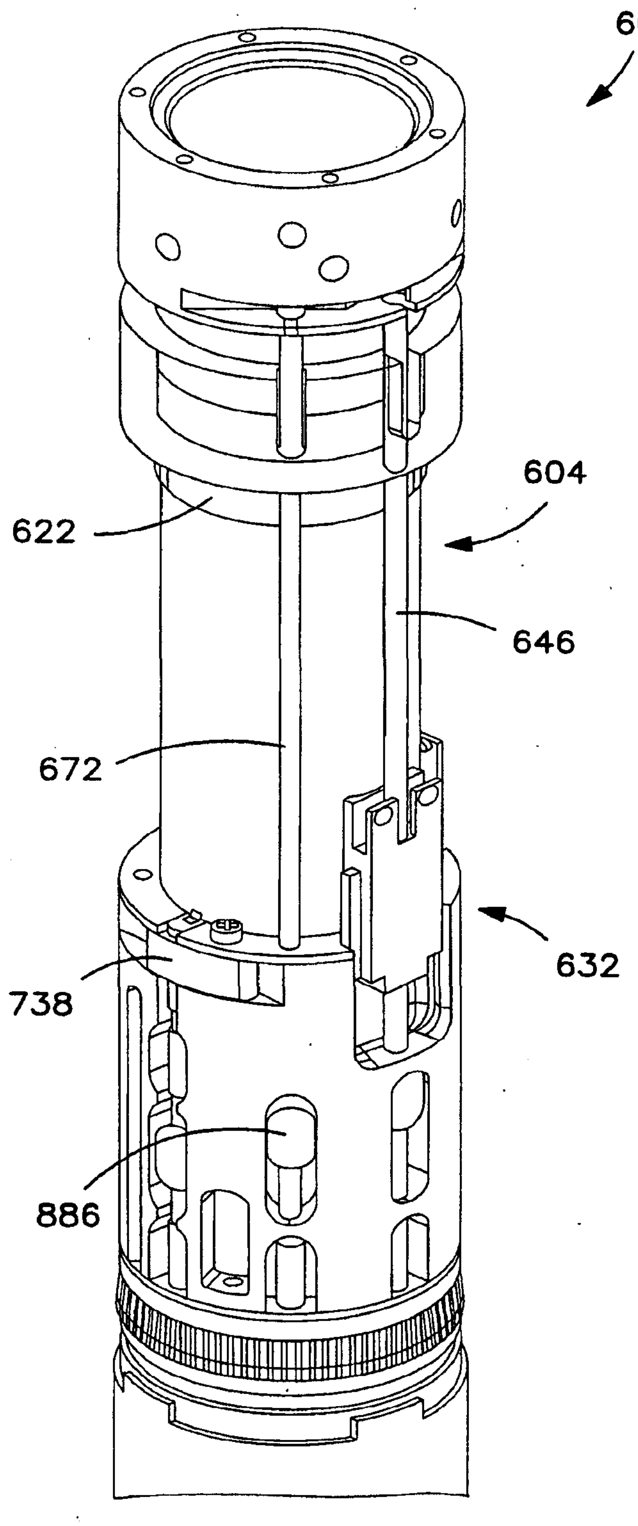

FIG. 8

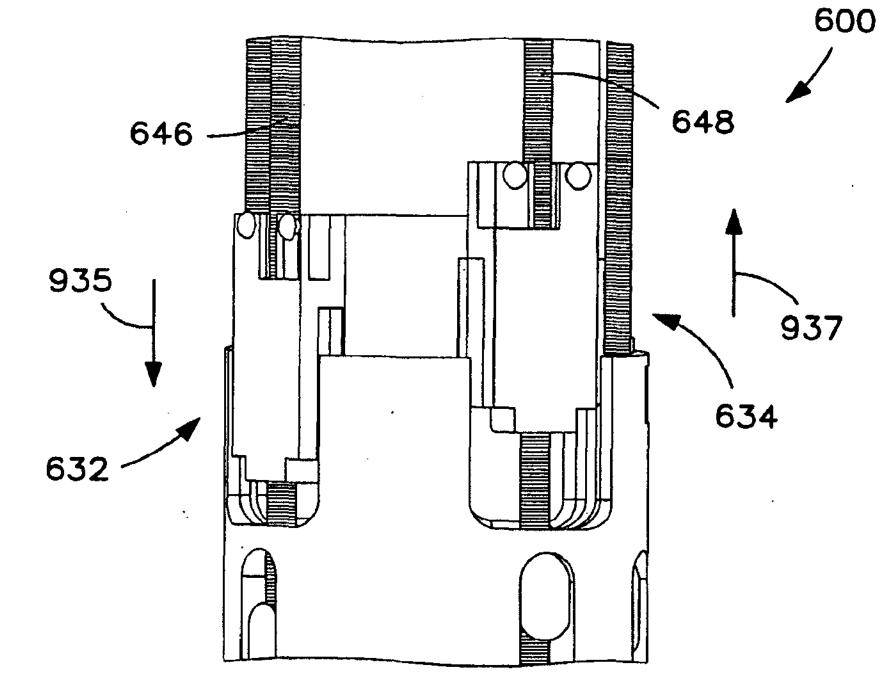

FIG. 9

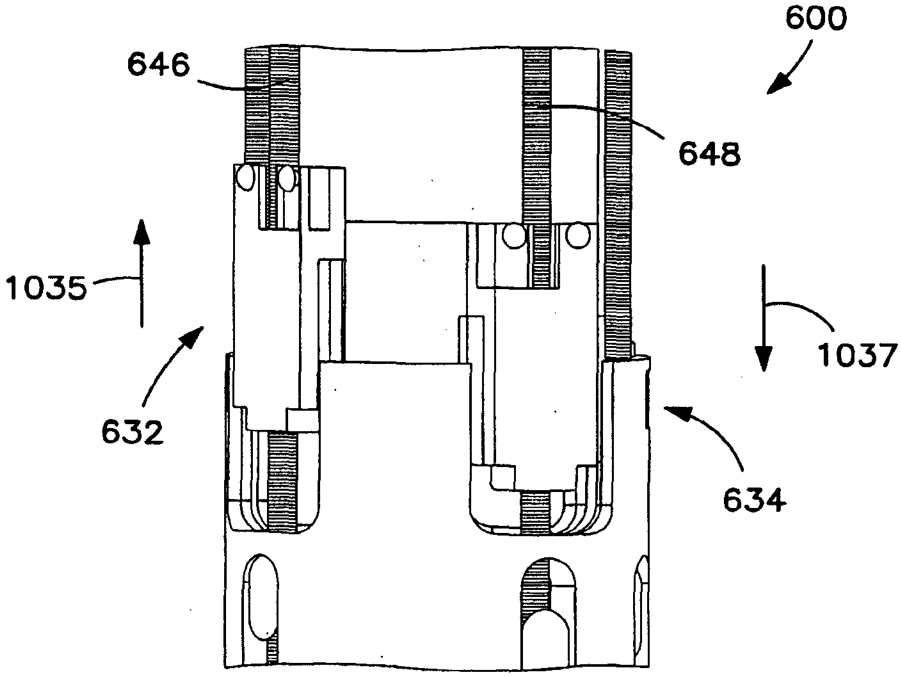

FIG. 10

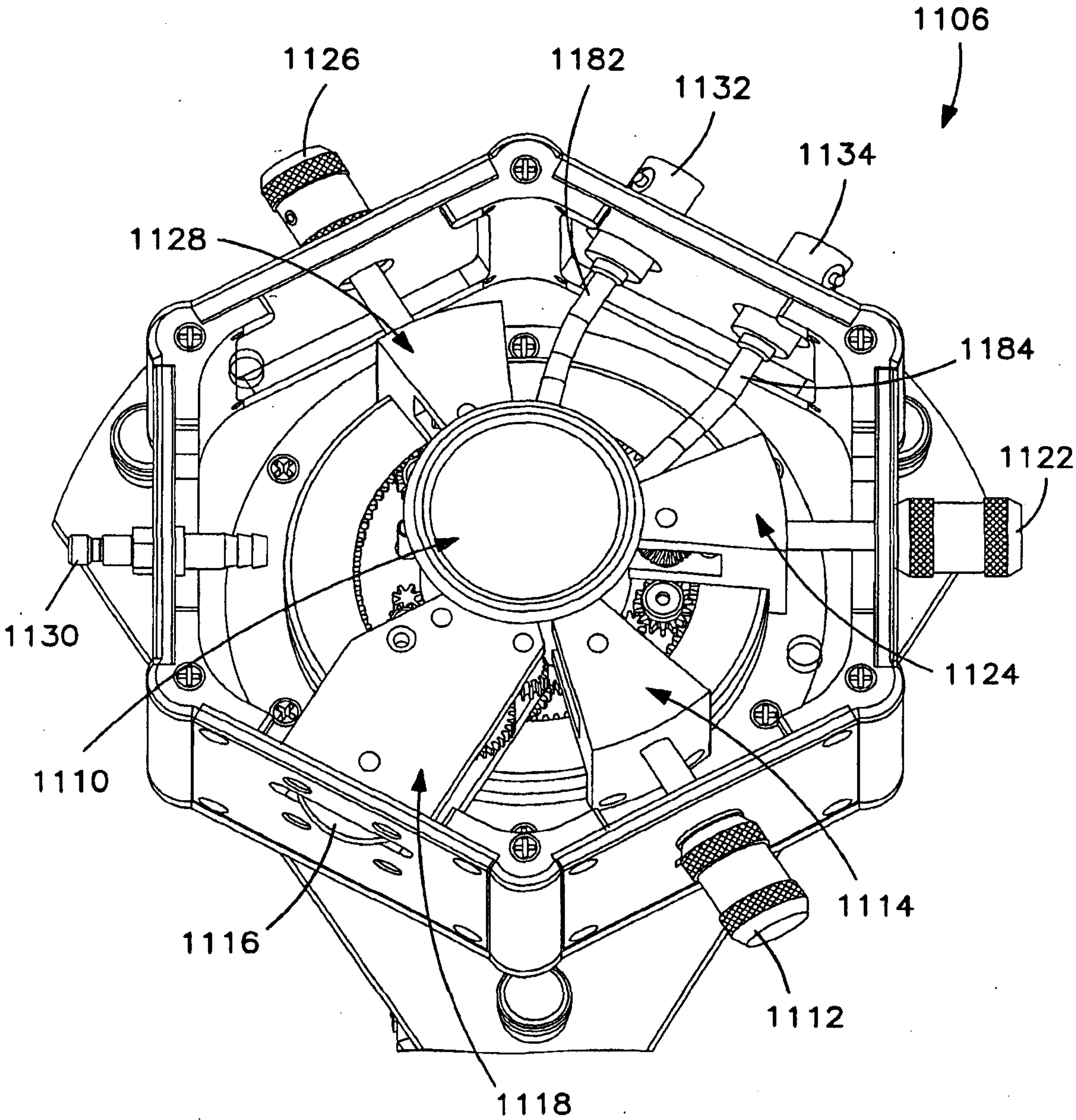
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FIG. 11

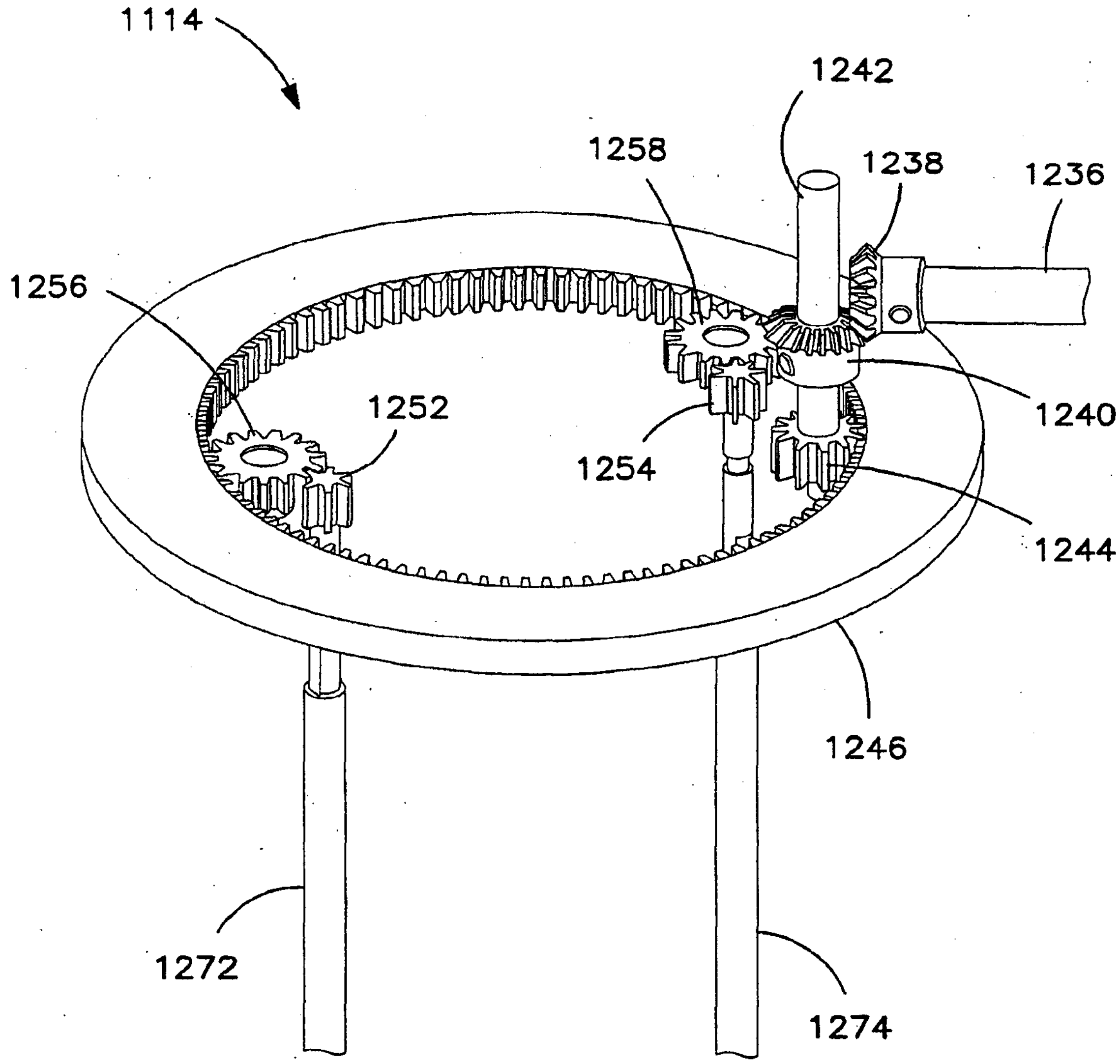
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FIG. 12

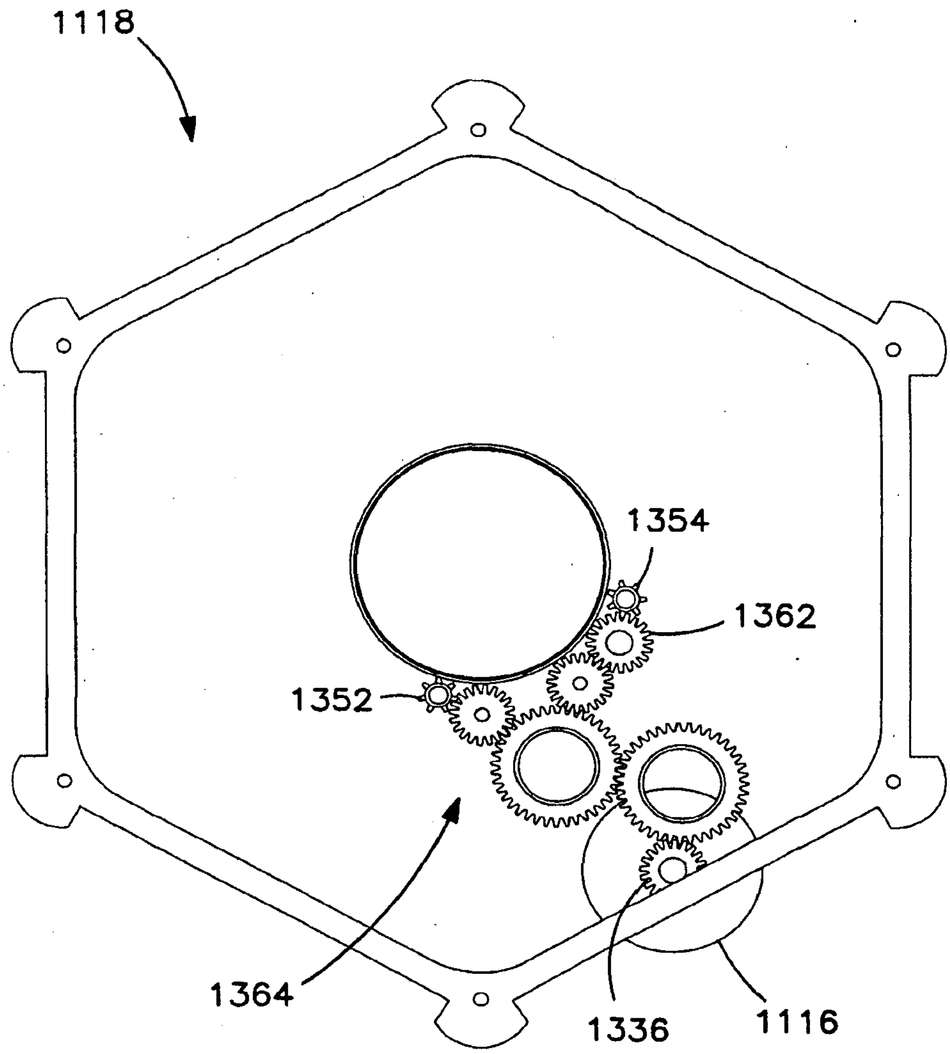

FIG. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2008/063310

A. CLASSIFICATION OF SUBJECT MATTER

A61B 5/055(2006.01)i, G01R 33/34(2006.01)i, G01V 3/00(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 8 A61B 5/055, G01R 33/28, G01R 33/34 and G01R 33/36

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

Korean Utility Models and application for Utility Models : IPC as above
Japanese Utility Models and application for Utility Models : IPC as above

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

eKIPASS (KIPO internal) & keyword : "quadrature"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 07-039539 A (HITACHI MEDICAL CORP.) 10 FEBRUARY 1995 See abstract and figures 1, 3	1-20
A	JP 2007-275164 A (HITACHI LTD.) 25 OCTOBER 2007 See abstract and figure 2	1-20
A	US 5483163 A (HAN WEN et al) 09 JANUARY 1996 See abstract	1-20

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 SEPTEMBER 2008 (30.09.2008)	**30 SEPTEMBER 2008 (30.09.2008)**

Name and mailing address of the ISA/KR

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Facsimile No. 82-42-472-7140

Authorized officer

KWON, Yongkyong

Telephone No. 82-42-481-5800

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2008/063310

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 07-039539 A	10.02.1995	None	
JP 2007-275164 A	25.10.2007	US 7414402	19.08.2008
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US 5483163 A	09.01.1996	None	