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Kasturi et al.

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(54) SYSTEM AND METHOD FOR LOW LOSS WIRELESS POWER TRANSMISSION

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(51) **Int. Cl.**

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H02J 7/02	(2006.01)
H02J 5/00	(2006.01)
H01F 27/42	(2006.01)

(52) **U.S. Cl.**

CPC ***H04B 5/0037*** (2013.01); ***H02J 5/005*** (2013.01); ***H02J 7/025*** (2013.01); ***H04B 5/0087*** (2013.01)

(58) **Field of Classification Search**

CPC H02J 7/025
USPC 307/104
See application file for complete search history.

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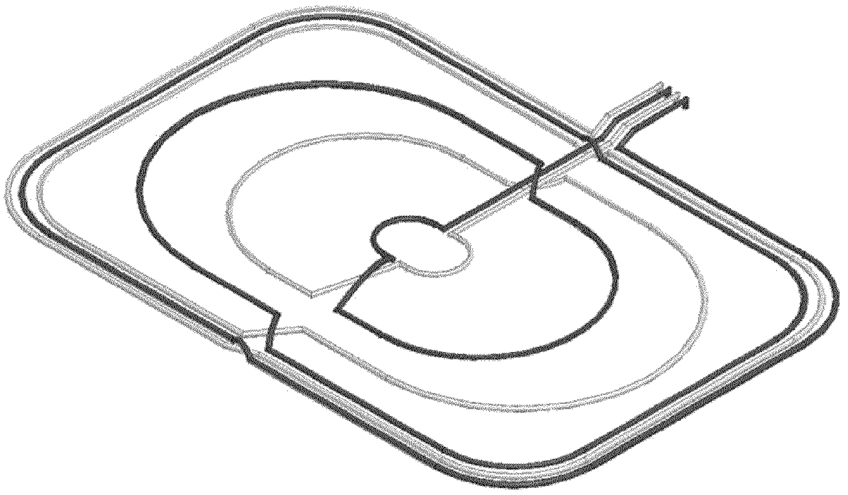
Primary Examiner — Robert Deberadinis

(74) *Attorney, Agent, or Firm* — Knobbe, Martens, Olson and Bear LLP

(57) ABSTRACT

Systems and methods for low loss wireless power transmission are described herein. In one aspect, a transmission coil for transmitting wireless power comprises a first and second spiral coil. Each spiral coil comprises a plurality of turns. A center of the first spiral coil to an outermost turn of the first spiral coil defines a first cross section, and a center of the second spiral coil to an outermost turn of the second spiral coil defines a second cross section. Portions of the first spiral coil along the first cross section and the second spiral coil along the second cross section have a mutual inductance with respect to a receive coil greater than 65% of a maximum mutual inductance along the first and second cross sections. The second spiral coil is counter-wound relative to the first spiral coil.

18 Claims, 10 Drawing Sheets



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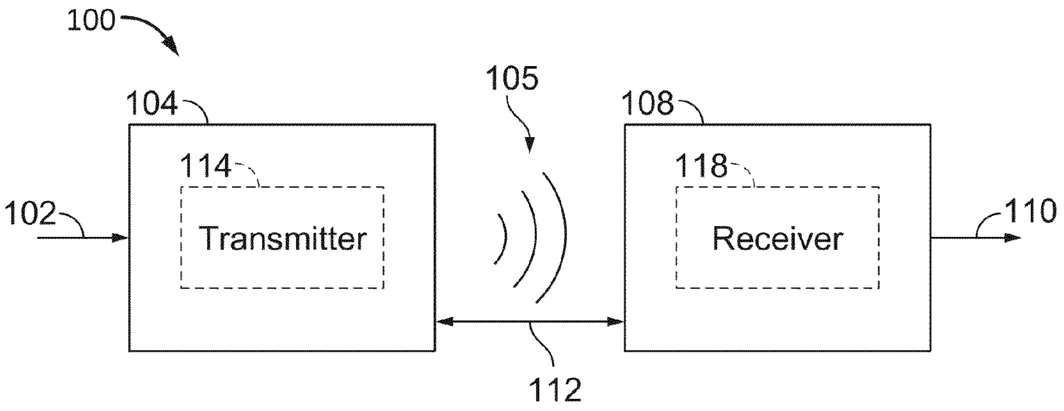


FIG. 1

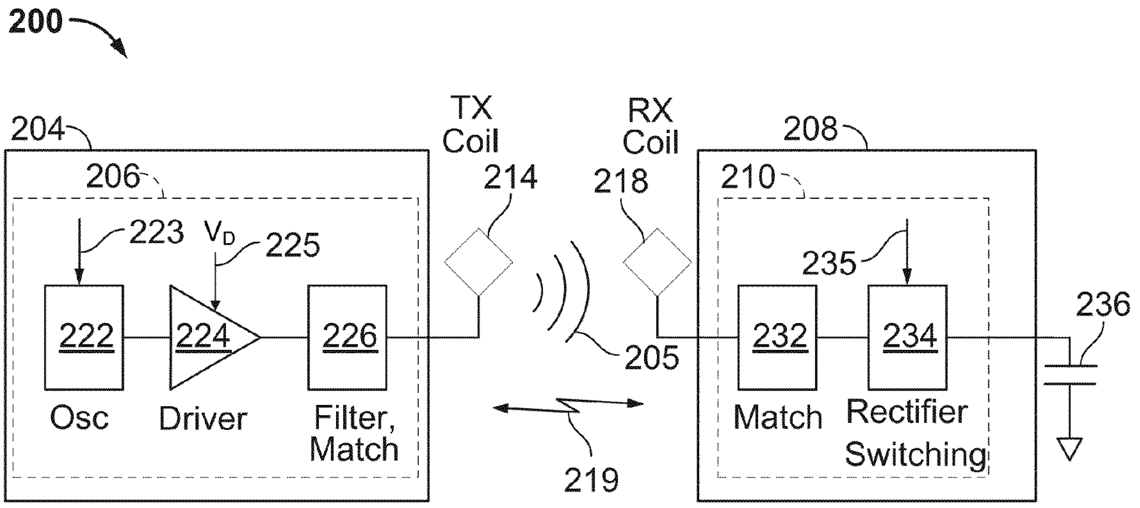


FIG. 2

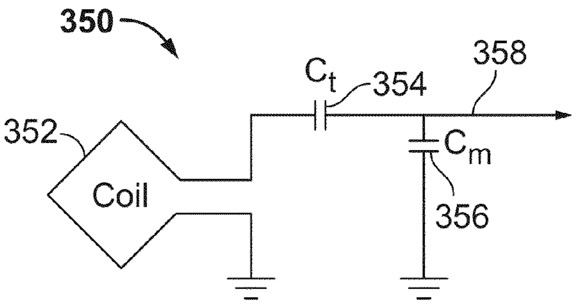
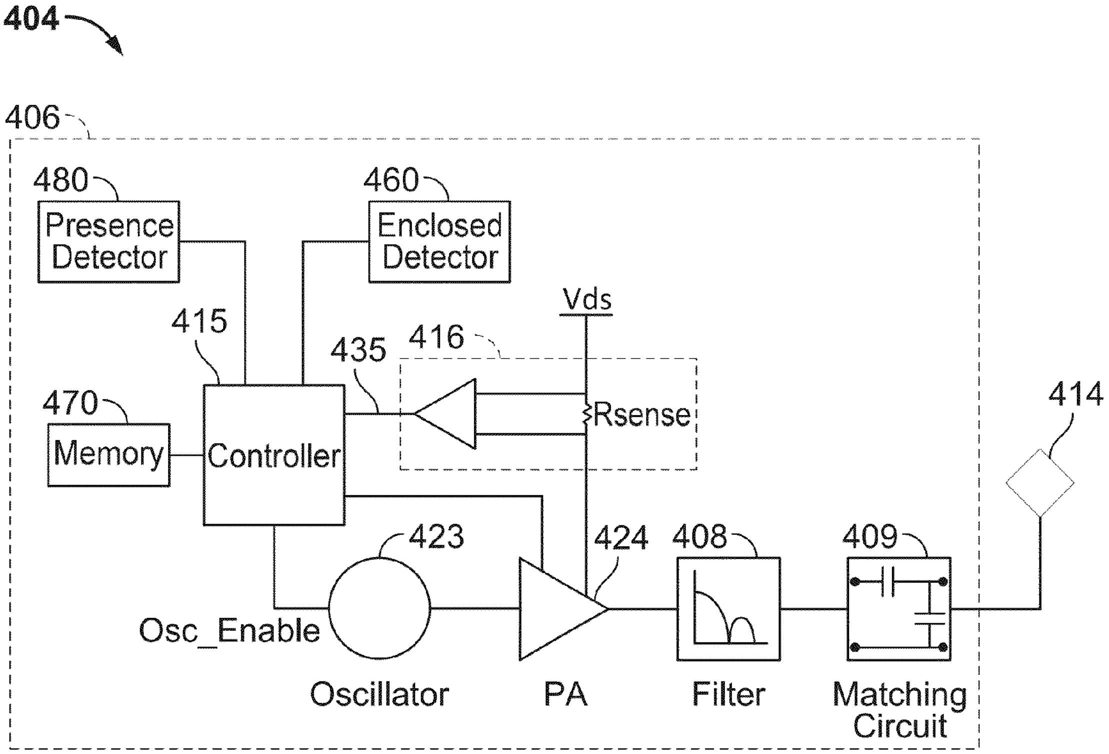


FIG. 3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406
480
Presence Detector
460
Enclosed Detector
Vds
415
435
416
470
Memory
Controller
Rsense
414
423
424
408
409
Osc_Enable
Oscillator
PA
Filter
Matching Circuit

FIG. 4

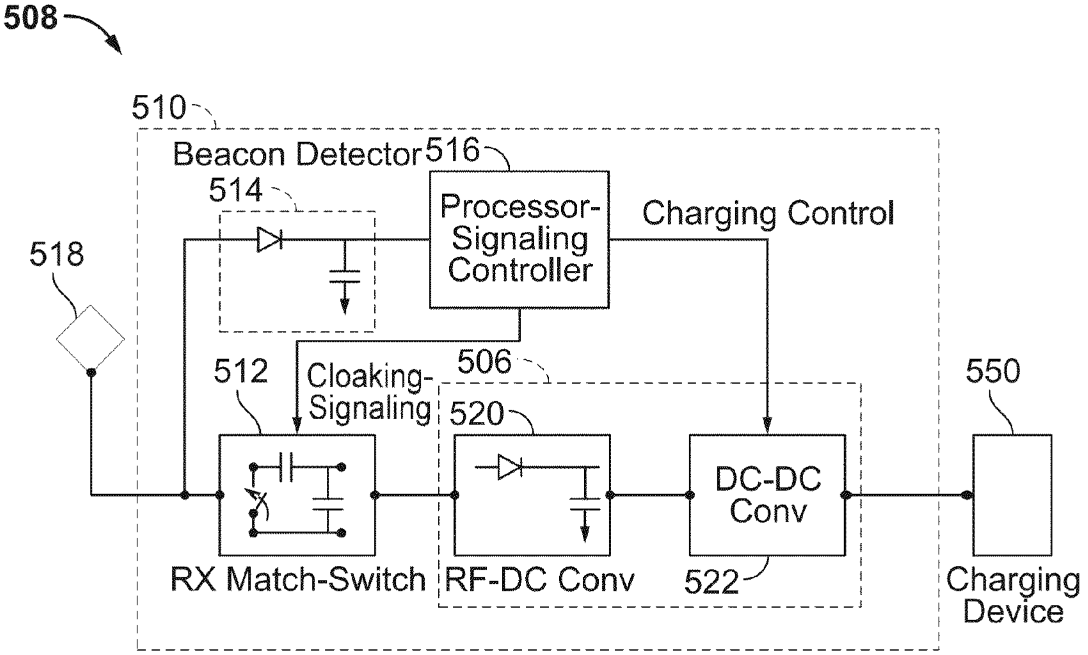

508
510
Beacon Detector
516
514
Processor-Signaling Controller
Charging Control
518
512
Cloaking-Signaling
506
520
DC-DC Conv
550
RX Match-Switch
RF-DC Conv
522
Charging Device

FIG. 5

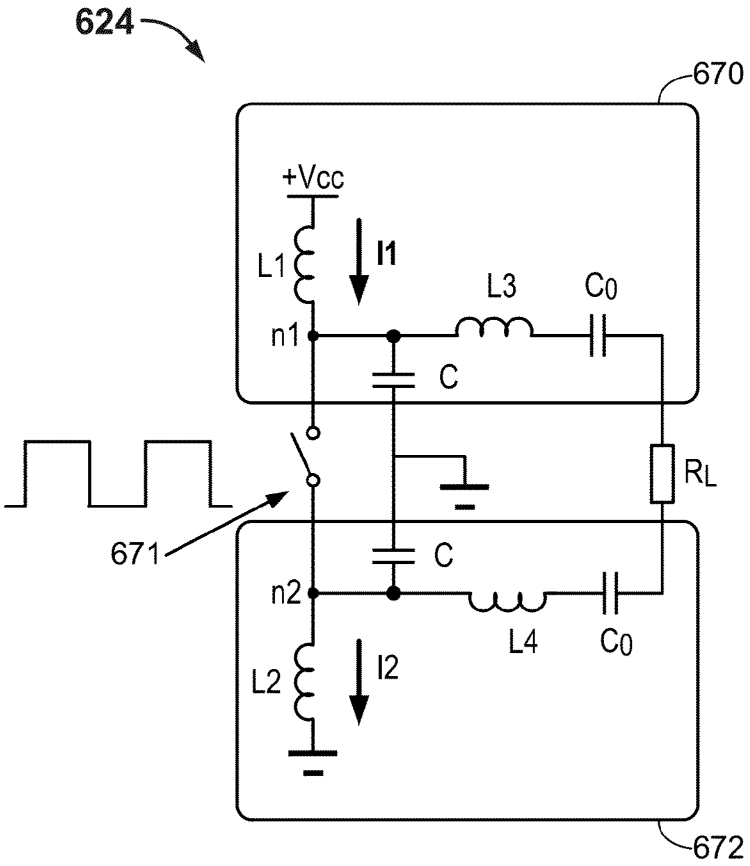
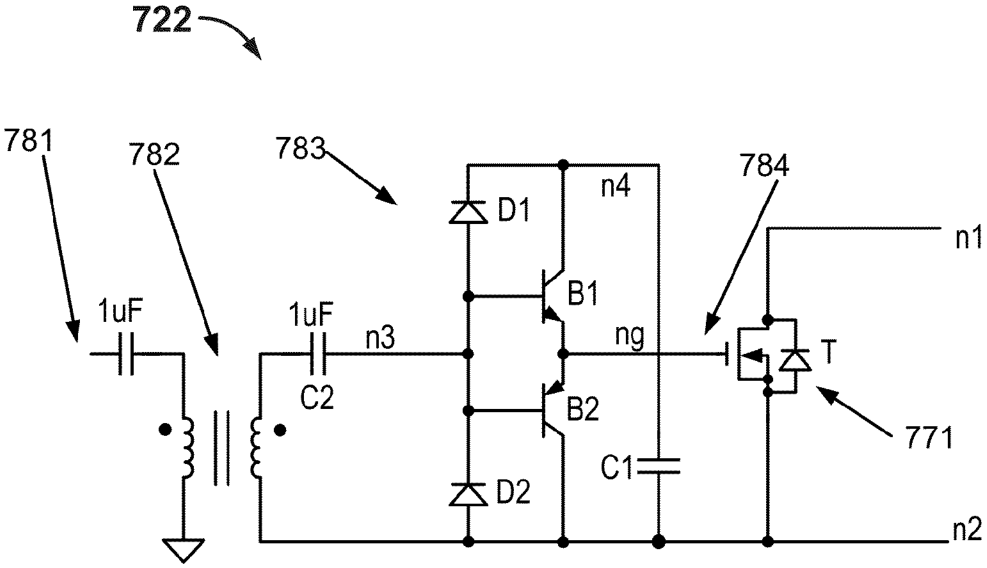

624
670
+Vcc
L1
I1
L3
C0
n1
C
RL
671
C
n2
L4
C0
L2
I2
672

FIG. 6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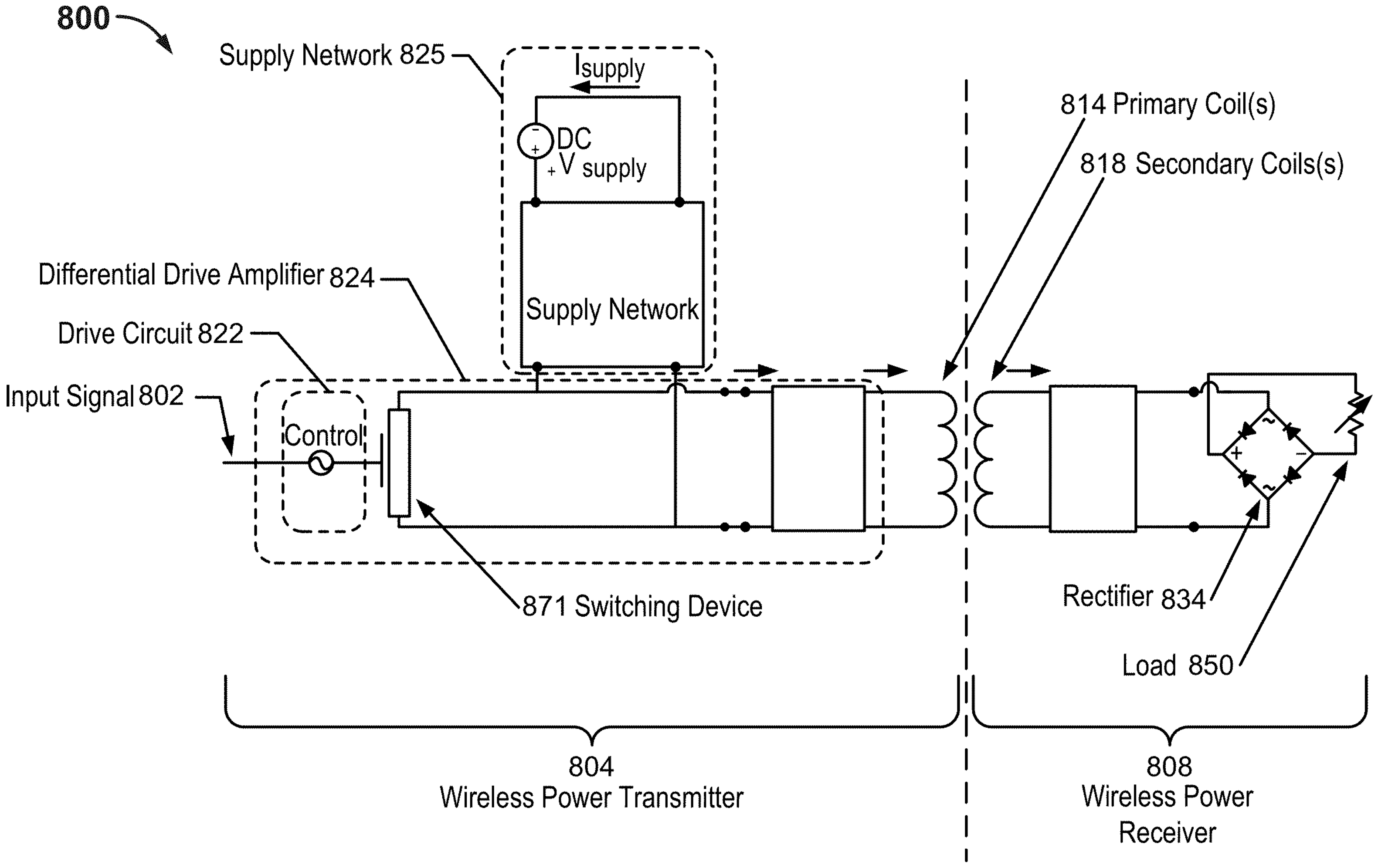
782
783
784
1uF
1uF
n3
C2
D1
n4
B1
ng
B2
T
771
n1
C1
D2
n2

FIG. 7


800
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Isupply
DC
V supply
Supply Network
Differential Drive Amplifier 824
Drive Circuit 822
Input Signal 802
Control
871 Switching Device
814 Primary Coil(s)
818 Secondary Coils(s)
Rectifier 834
Load 850
804
Wireless Power Transmitter
808
Wireless Power Receiver

FIG. 8

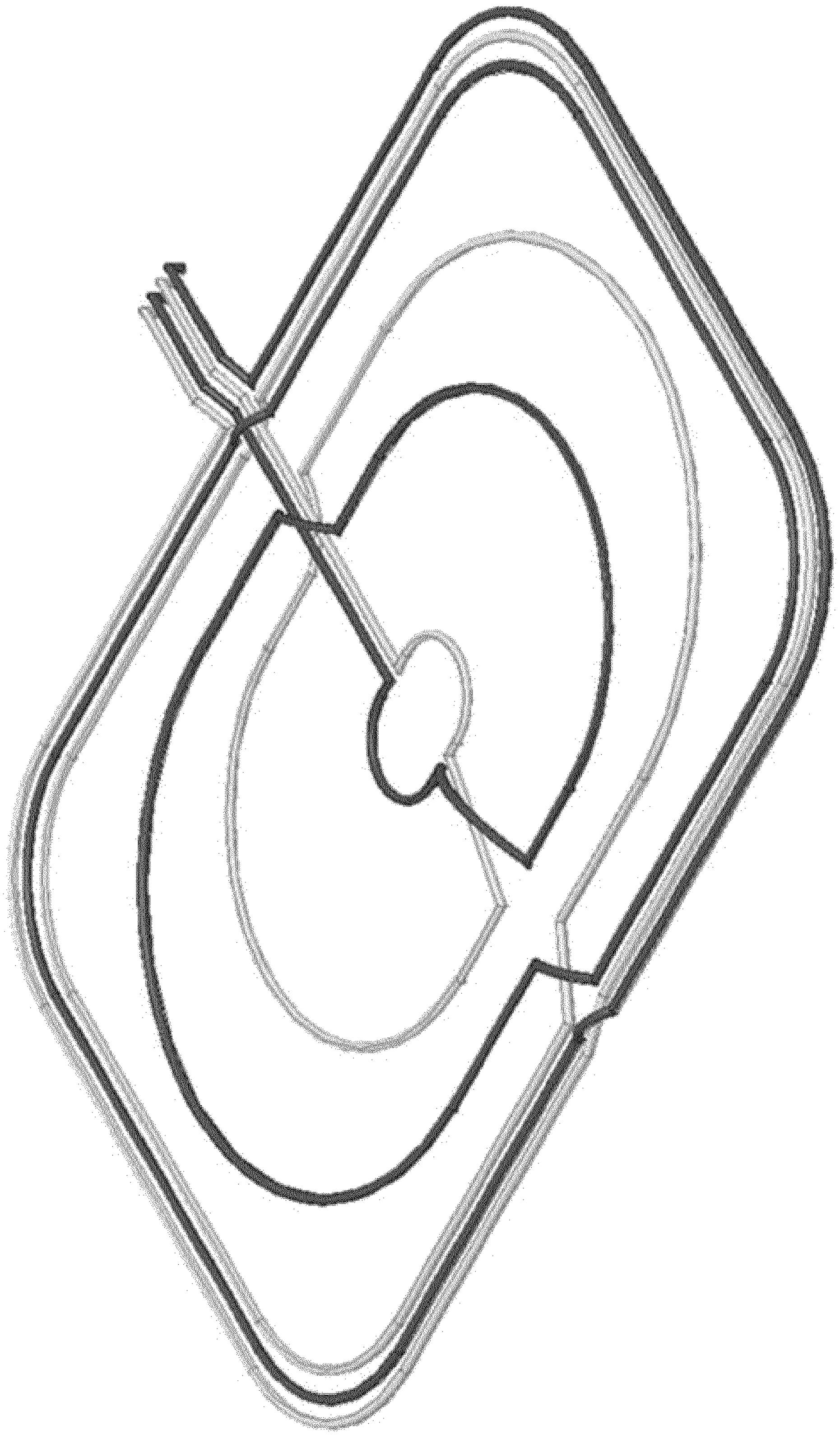


FIG. 9

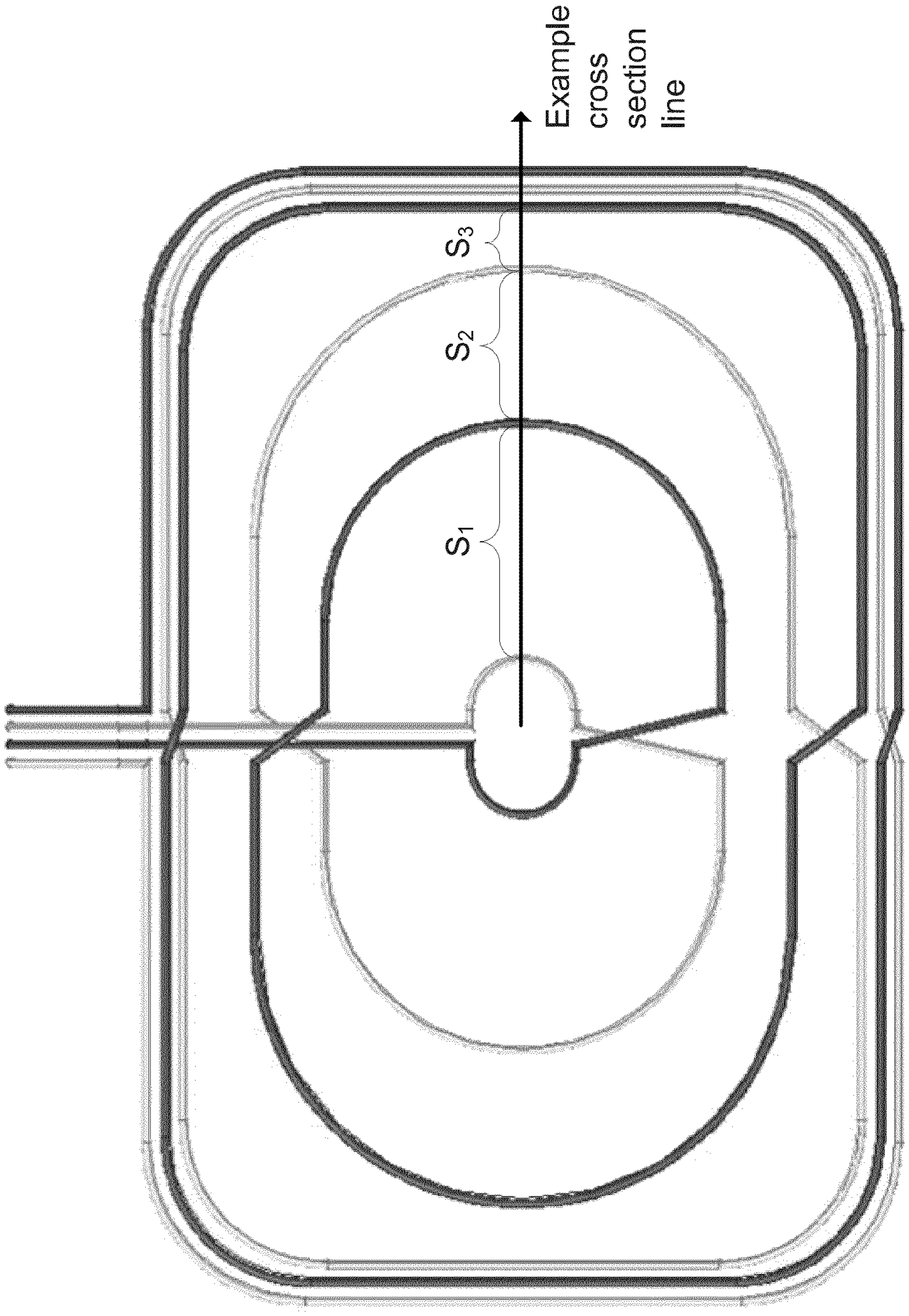


FIG. 10

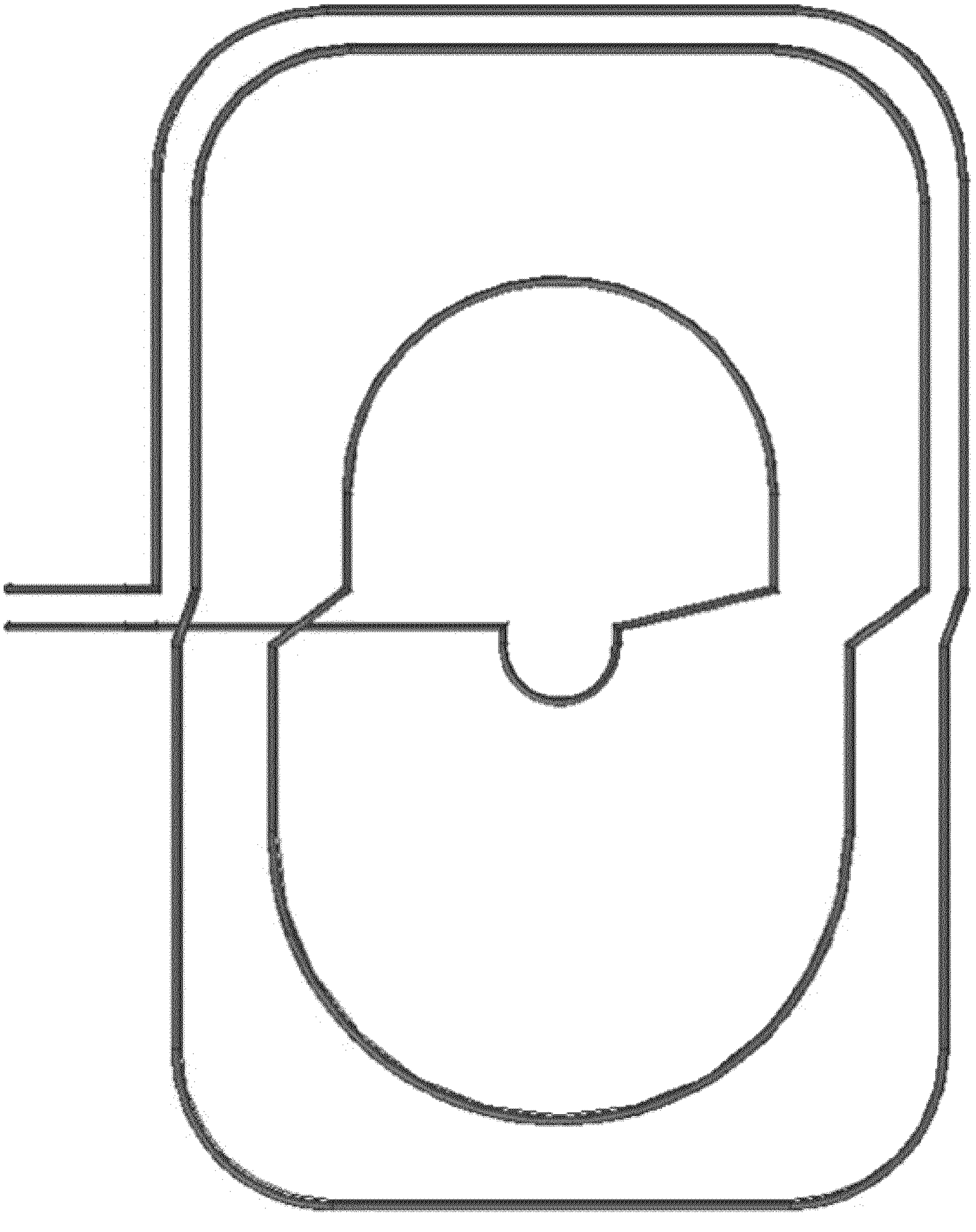


FIG. 11

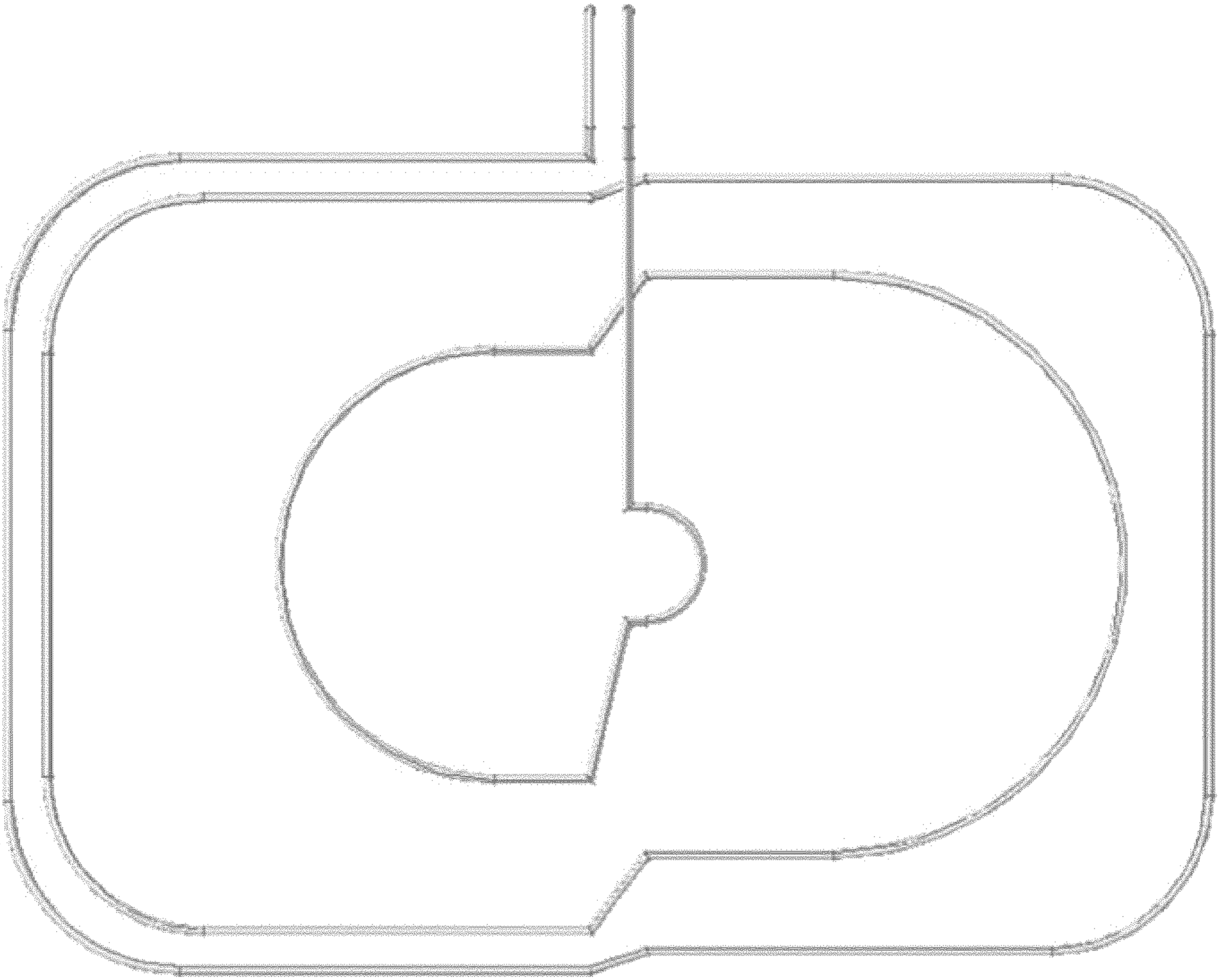
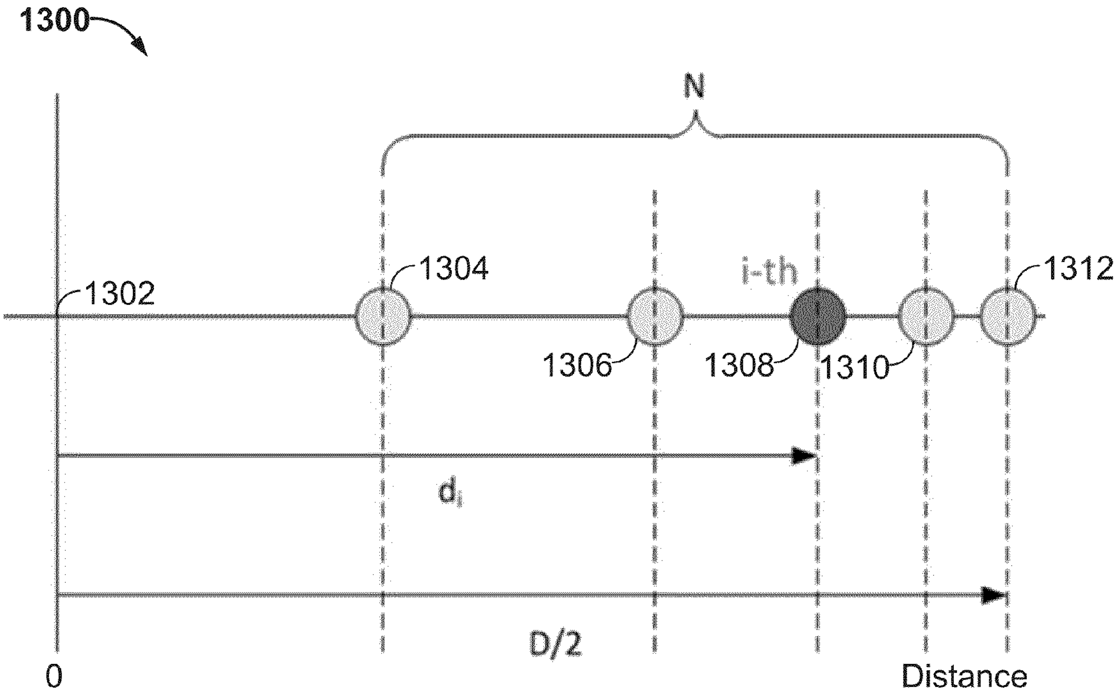


FIG. 12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N
1304
1302
i-th
1312
1306
1308
1310
d_i
D/2
0
Distance

FIG. 13

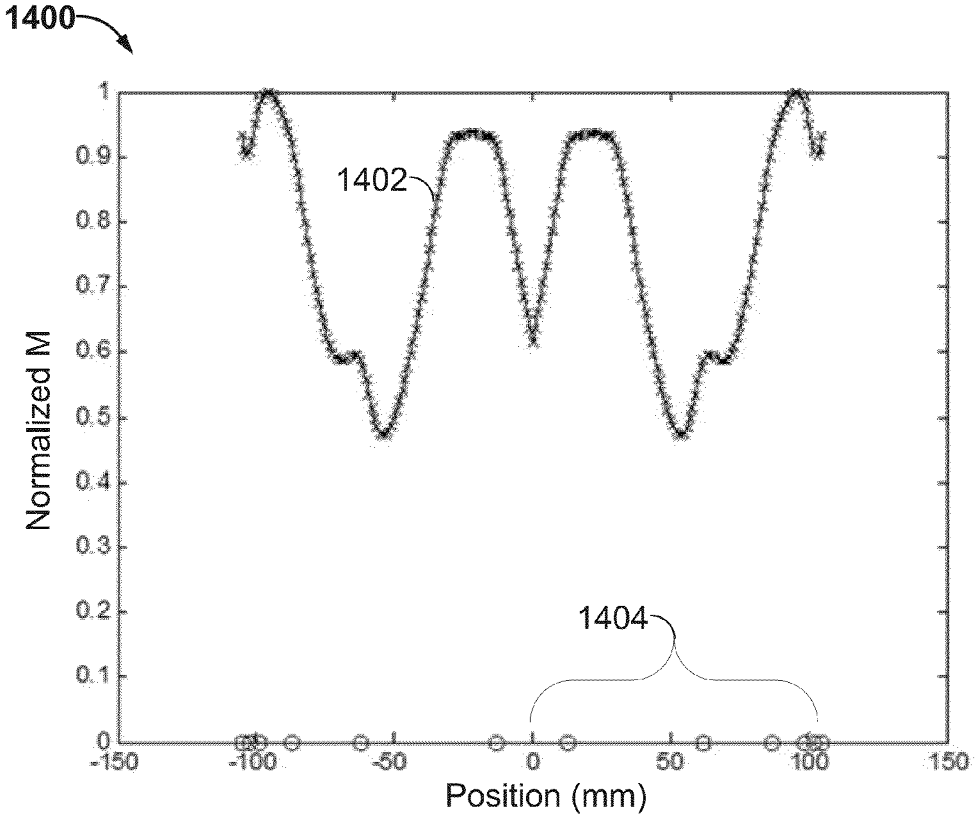
1400
1402
1404
Normalized M
Position (mm)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-150
-100
-50
0
50
100
150

FIG. 14

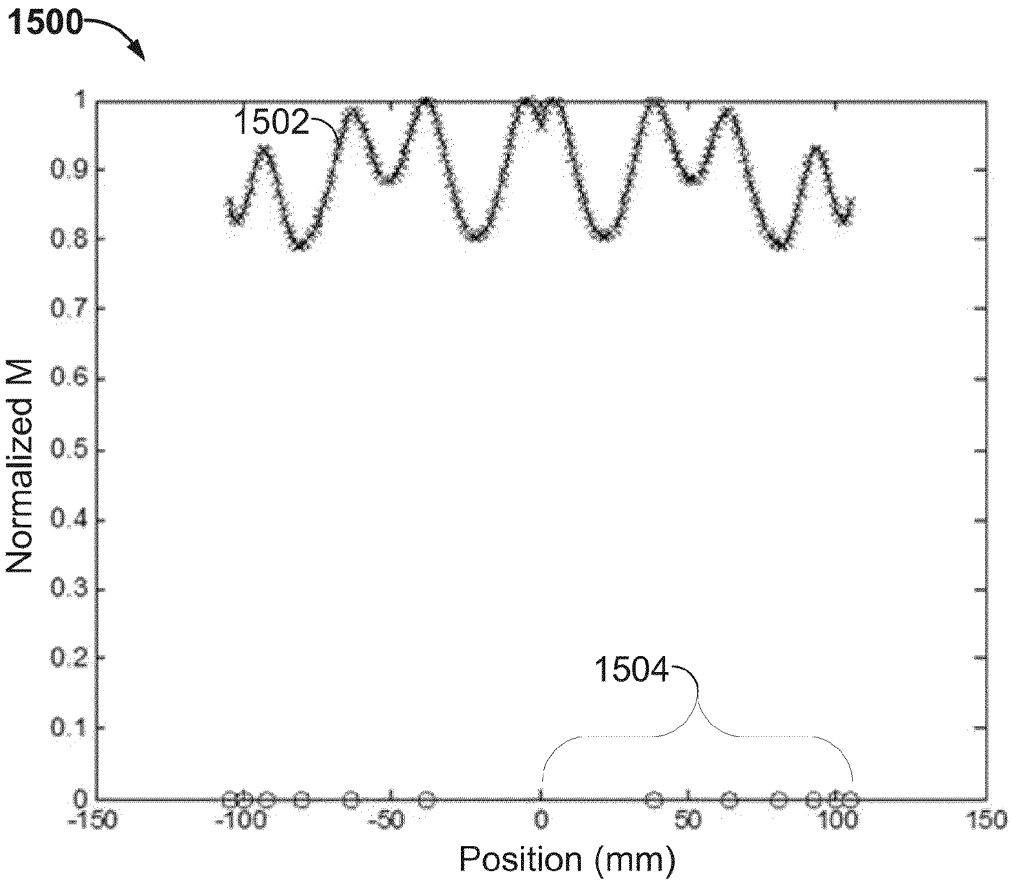
1500
1502
1504
Normalized M
Position (mm)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-150
-100
-50
0
50
100
150

FIG. 15

SYSTEM AND METHOD FOR LOW LOSS WIRELESS POWER TRANSMISSION

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority benefit under 35 U.S.C. §119(e) to U.S. Provisional Patent Application No. 61/576,885 entitled "SYSTEMS FOR LOW LOSS WIRELESS POWER TRANSMISSION" filed on Dec. 16, 2011, the disclosure of which is hereby incorporated by reference in its entirety.

FIELD

The present invention relates generally to wireless power. More specifically, the disclosure is directed to a transmitting coil for low loss wireless power transmission.

BACKGROUND

An increasing number and variety of electronic devices are powered via rechargeable batteries. Such devices include mobile phones, portable music players, laptop computers, tablet computers, computer peripheral devices, communication devices (e.g., Bluetooth devices), digital cameras, hearing aids, and the like. While battery technology has improved, battery-powered electronic devices increasingly require and consume greater amounts of power. As such, these devices constantly require recharging.

Rechargeable devices are often charged via wired connections through cables or other similar connectors that are physically connected to a power supply. Cables and similar connectors may sometimes be inconvenient or cumbersome and have other drawbacks. Wireless charging systems that are capable of transferring power in free space to be used to charge rechargeable electronic devices or provide power to electronic devices may overcome some of the deficiencies of wired charging solutions. As such, wireless power transfer systems and methods that efficiently and safely transfer power to electronic devices are desirable.

SUMMARY

Various implementations of systems, methods and devices within the scope of the appended claims each have several aspects, no single one of which is solely responsible for the desirable attributes described herein. Without limiting the scope of the appended claims, some prominent features are described herein.

Details of one or more implementations of the subject matter described in this specification are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages will become apparent from the description, the drawings, and the claims. Note that the relative dimensions of the following figures may not be drawn to scale.

One aspect of the disclosure provides a transmission coil for transmitting wireless power, comprising a first spiral coil and a second spiral coil. The first spiral coil includes a plurality of turns. A center of the first spiral coil to an outermost turn of the first spiral coil defines a first cross section. The second spiral coil includes a plurality of turns. A center of the second spiral coil to an outermost turn of the second spiral coil defines a second cross section. Portions of the first spiral coil along the first cross section and the second spiral coil along the second cross section have a mutual inductance with

respect to a receive coil greater than 65% of a maximum mutual inductance along the first and second cross sections. The second spiral coil counter-wound relative to the first spiral coil.

Another aspect of the disclosure provides a method for transmitting wireless power. The method includes driving with electrical current a first spiral coil that includes a plurality of turns. A center of the first spiral coil to an outermost turn of the first spiral coil defines a first cross section. The method further includes driving with electrical current a second spiral coil that includes a plurality of turns. A center of the second spiral coil to an outermost turn of the second spiral coil defines a second cross section. Portions of the first spiral coil along the first cross section and the second spiral coil along the second cross section have a mutual inductance with respect to a receive coil greater than 65% of a maximum mutual inductance along the first and second cross sections. The second spiral coil is counter-wound relative to the first spiral coil.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a functional block diagram of an exemplary wireless power transfer system, in accordance with exemplary embodiments.

FIG. **2** is a functional block diagram of exemplary components that may be used in the wireless power transfer system of FIG. **1**, in accordance with various exemplary embodiments.

FIG. **3** is a schematic diagram of a portion of transmit circuitry or receive circuitry of FIG. **2** including a transmit or receive coil, in accordance with exemplary embodiments.

FIG. **4** is a functional block diagram of a transmitter that may be used in the wireless power transfer system of FIG. **1**, in accordance with exemplary embodiments.

FIG. **5** is a functional block diagram of a receiver that may be used in the wireless power transfer system of FIG. **1**, in accordance with exemplary embodiments.

FIG. **6** is a schematic diagram of single switching device differential drive amplifier in accordance with various aspects.

FIG. **7** illustrates an exemplary drive circuit in accordance with various aspects.

FIG. **8** illustrates an exemplary wireless power system including a wireless transmitter and a wireless receiver.

FIGS. **9** and **10** illustrate exemplary two coil arrangements for planar voltage co-location according to various aspects.

FIG. **11** illustrates an exemplary coil layout according to various aspects.

FIG. **12** illustrates another exemplary coil layout according to various aspects.

FIG. **13** illustrates a cross section of an exemplary coil arrangement.

FIG. **14** is a plot of normalized mutual inductance versus position for an exemplary coil arrangement.

FIG. **15** is a plot of normalized mutual inductance versus position for another exemplary coil arrangement.

The various features illustrated in the drawings may not be drawn to scale. Accordingly, the dimensions of the various features may be arbitrarily expanded or reduced for clarity. In addition, some of the drawings may not depict all of the components of a given system, method or device. Finally, like reference numerals may be used to denote like features throughout the specification and figures.

DETAILED DESCRIPTION

The detailed description set forth below in connection with the appended drawings is intended as a description of exemplary embodiments of the invention and is not intended to represent the only embodiments in which the invention may be practiced. The term "exemplary" used throughout this description means "serving as an example, instance, or illustration," and should not necessarily be construed as preferred or advantageous over other exemplary embodiments. The detailed description includes specific details for the purpose of providing a thorough understanding of the exemplary embodiments of the invention. The exemplary embodiments of the invention may be practiced without these specific details. In some instances, well-known structures and devices are shown in block diagram form in order to avoid obscuring the novelty of the exemplary embodiments presented herein.

Wirelessly transferring power may refer to transferring any form of energy associated with electric fields, magnetic fields, electromagnetic fields, or otherwise from a transmitter to a receiver without the use of physical electrical conductors (e.g., power may be transferred through free space). The power output into a wireless field (e.g., a magnetic field) may be received, captured by, or coupled by a "receiving coil" to achieve power transfer.

FIG. **1** is a functional block diagram of an exemplary wireless power transfer system **100**, in accordance with exemplary embodiments of the invention. Input power **102** may be provided to a transmitter **104** from a power source (not shown) for generating a field **105** for providing energy transfer at a power level sufficient to charge or power a device (not shown). A receiver **108** may couple to the field **105** and generate output power **110** for storing or consumption by the device coupled to the output power **110**. Both the transmitter **104** and the receiver **108** are separated by a distance **112**. In one exemplary embodiment, transmitter **104** and receiver **108** are configured according to a mutual resonant relationship. When the resonant frequency of receiver **108** and the resonant frequency of transmitter **104** are substantially the same or very close, transmission losses between the transmitter **104** and the receiver **108** are minimal. As such, wireless power transfer may be provided over larger distance in contrast to purely inductive solutions that may require large coils that require coils to be very close (e.g., millimeters). Resonant inductive coupling techniques may thus allow for improved efficiency and power transfer over various distances and with a variety of inductive coil configurations.

The receiver **108** may receive power when the receiver **108** is located in an energy field **105** produced by the transmitter **104**. The field **105** corresponds to a region where energy output by the transmitter **104** may be captured by a receiver **105**. In some cases, the field **105** may correspond to the "near-field" of the transmitter **104** as will be further described below. The transmitter **104** may include a transmit coil **114** for outputting an energy transmission. The receiver **108** further includes a receive coil **118** for receiving or capturing energy from the energy transmission. The near-field may correspond to a region in which there are strong reactive fields resulting from the currents and charges in the transmit coil **114** that minimally radiate power away from the transmit coil **114**. In some cases the near-field may correspond to a region that is within about one wavelength (or a fraction thereof) of the transmit coil **114**. The transmit and receive coils **114** and **118** are sized according to applications and devices to be associated therewith. As described above, efficient energy transfer may occur by coupling a large portion of the energy in a field **105** of the transmit coil **114** to a receive coil **118** rather than propagating most of the energy in an electromagnetic wave to the far field. When positioned within the field **105**, a "coupling mode" may be developed between the transmit coil **114** and the receive coil **118**. The area around the transmit and receive coils **114** and **118** where this coupling may occur is referred to herein as a coupling-mode region.

FIG. **2** is a functional block diagram of exemplary components that may be used in the wireless power transfer system **100** of FIG. **1**, in accordance with various exemplary embodiments of the invention. The transmitter **204** may include transmit circuitry **206** that may include an oscillator **222**, a driver circuit **224**, and a filter and matching circuit **226**. The oscillator **222** may be configured to generate a signal at a desired frequency, such as 468.75 KHz, 6.78 MHz or 13.56 MHz, that may be adjusted in response to a frequency control signal **223**. The oscillator signal may be provided to a driver circuit **224** configured to drive the transmit coil **214** at, for example, a resonant frequency of the transmit coil **214**. The driver circuit **224** may be a switching amplifier configured to receive a square wave from the oscillator **222** and output a sine wave. For example, the driver circuit **224** may be a class E amplifier. A filter and matching circuit **226** may be also included to filter out harmonics or other unwanted frequencies and match the impedance of the transmitter **204** to the transmit coil **214**.

The receiver **208** may include receive circuitry **210** that may include a matching circuit **232** and a rectifier and switching circuit **234** to generate a DC power output from an AC power input to charge a battery **236** as shown in FIG. **2** or to power a device (not shown) coupled to the receiver **108**. The matching circuit **232** may be included to match the impedance of the receive circuitry **210** to the receive coil **218**. The receiver **208** and transmitter **204** may additionally communicate on a separate communication channel **219** (e.g., Bluetooth, zigbee, cellular, etc). The receiver **208** and transmitter **204** may alternatively communicate via in-band signaling using characteristics of the wireless field **206**.

As described more fully below, receiver **208**, that may initially have a selectively disablable associated load (e.g., battery **236**), may be configured to determine whether an amount of power transmitted by transmitter **204** and receiver by receiver **208** is appropriate for charging a battery **236**. Further, receiver **208** may be configured to enable a load (e.g., battery **236**) upon determining that the amount of power is appropriate. In some embodiments, a receiver **208** may be configured to directly utilize power received from a wireless power transfer field without charging of a battery **236**. For example, a communication device, such as a near-field communication (NFC) or radio-frequency identification device (RFID may be configured to receive power from a wireless power transfer field and communicate by interacting with the wireless power transfer field and/or utilize the received power to communicate with a transmitter **204** or other devices.

FIG. **3** is a schematic diagram of a portion of transmit circuitry **206** or receive circuitry **210** of FIG. **2** including a transmit or receive coil **352**, in accordance with exemplary embodiments of the invention. As illustrated in FIG. **3**, transmit or receive circuitry **350** used in exemplary embodiments may include a coil **352**. The coil may also be referred to or be configured as a "loop" antenna **352**. The coil **352** may also be referred to herein or be configured as a "magnetic" antenna or an induction coil. The term "coil" is intended to refer to a component that may wirelessly output or receive energy for coupling to another "coil." The coil may also be referred to as an "antenna" of a type that is configured to wirelessly output or receive power. The coil **352** may be configured to include an air core or a physical core such as a ferrite core (not shown). Air core loop coils may be more tolerable to extraneous physical devices placed in the vicinity of the core. Furthermore, an air core loop coil **352** allows the placement of other components within the core area. In addition, an air core loop may more readily enable placement of the receive coil **218** (FIG. **2**) within a plane of the transmit coil **214** (FIG. **2**) where the coupled-mode region of the transmit coil **214** (FIG. **2**) may be more powerful.

As stated, efficient transfer of energy between the transmitter **104** and receiver **108** may occur during matched or nearly matched resonance between the transmitter **104** and the receiver **108**. However, even when resonance between the transmitter **104** and receiver **108** are not matched, energy may be transferred, although the efficiency may be affected. Transfer of energy occurs by coupling energy from the field **105** of the transmitting coil to the receiving coil residing in the neighborhood where this field **105** is established rather than propagating the energy from the transmitting coil into free space.

The resonant frequency of the loop or magnetic coils is based on the inductance and capacitance. Inductance may be simply the inductance created by the coil **352**, whereas, capacitance may be added to the coil's inductance to create a resonant structure at a desired resonant frequency. As a non-limiting example, capacitor **352** and capacitor **354** may be added to the transmit or receive circuitry **350** to create a resonant circuit that selects a signal **356** at a resonant frequency. Accordingly, for larger diameter coils, the size of capacitance needed to sustain resonance may decrease as the diameter or inductance of the loop increases. Furthermore, as the diameter of the coil increases, the efficient energy transfer area of the near-field may increase. Other resonant circuits formed using other components are also possible. As another non-limiting example, a capacitor may be placed in parallel between the two terminals of the coil **350**. For transmit coils, a signal **358** with a frequency that substantially corresponds to the resonant frequency of the coil **352** may be an input to the coil **352**.

In one embodiment, the transmitter **104** may be configured to output a time varying magnetic field with a frequency corresponding to the resonant frequency of the transmit coil **114**. When the receiver is within the field **105**, the time varying magnetic field may induce a current in the receive coil **118**. As described above, if the receive coil **118** is configured to be resonant at the frequency of the transmit coil **118**, energy may be efficiently transferred. The AC signal induced in the receive coil **118** may be rectified as described above to produce a DC signal that may be provided to charge or to power a load.

FIG. **4** is a functional block diagram of a transmitter **404** that may be used in the wireless power transfer system of FIG. **1**, in accordance with exemplary embodiments of the invention. The transmitter **404** may include transmit circuitry **406** and a transmit coil **414**. The transmit coil **414** may be the coil **352** as shown in FIG. **3**. Transmit circuitry **406** may provide RF power to the transmit coil **414** by providing an oscillating signal resulting in generation of energy (e.g., magnetic flux) about the transmit coil **414**. Transmitter **404** may operate at any suitable frequency. By way of example, transmitter **404** may operate at the 13.56 MHz ISM band.

Transmit circuitry **406** may include a fixed impedance matching circuit **409** for matching the impedance of the transmit circuitry **406** (e.g., 50 ohms) to the transmit coil **414** and a low pass filter (LPF) **408** configured to reduce harmonic emissions to levels to prevent self-jamming of devices coupled to receivers **108** (FIG. **1**). Other exemplary embodiments may include different filter topologies, including but not limited to, notch filters that attenuate specific frequencies while passing others and may include an adaptive impedance match, that may be varied based on measurable transmit metrics, such as output power to the coil **414** or DC current drawn by the driver circuit **424**. Transmit circuitry **406** further includes a driver circuit **424** configured to drive an RF signal as determined by an oscillator **423**. The transmit circuitry **406** may be comprised of discrete devices or circuits, or alternately, may be comprised of an integrated assembly. An exemplary RF power output from transmit coil **414** may be on the order of 2.5 Watts.

Transmit circuitry **406** may further include a controller **415** for selectively enabling the oscillator **423** during transmit phases (or duty cycles) for specific receivers, for adjusting the frequency or phase of the oscillator **423**, and for adjusting the output power level for implementing a communication protocol for interacting with neighboring devices through their attached receivers. It is noted that the controller **415** may also be referred to herein as processor **415**. Adjustment of oscillator phase and related circuitry in the transmission path may allow for reduction of out of band emissions, especially when transitioning from one frequency to another.

The transmit circuitry **406** may further include a load sensing circuit **416** for detecting the presence or absence of active receivers in the vicinity of the near-field generated by transmit coil **414**. By way of example, a load sensing circuit **416** monitors the current flowing to the driver circuit **424**, that may be affected by the presence or absence of active receivers in the vicinity of the field generated by transmit coil **414** as will be further described below. Detection of changes to the loading on the driver circuit **424** are monitored by controller **415** for use in determining whether to enable the oscillator **423** for transmitting energy and to communicate with an active receiver. As described more fully below, a current measured at the driver circuit **424** may be used to determine whether an invalid device is positioned within a wireless power transfer region of the transmitter **404**.

The transmit coil **414** may be implemented with a Litz wire or as an antenna strip with the thickness, width and metal type selected to keep resistive losses low. In a one implementation, the transmit coil **414** may generally be configured for association with a larger structure such as a table, mat, lamp or other less portable configuration. Accordingly, the transmit coil **414** generally may not need "turns" in order to be of a practical dimension. An exemplary implementation of a transmit coil **414** may be "electrically small" (i.e., fraction of the wavelength) and tuned to resonate at lower usable frequencies by using capacitors to define the resonant frequency.

The transmitter **404** may gather and track information about the whereabouts and status of receiver devices that may be associated with the transmitter **404**. Thus, the transmit circuitry **406** may include a presence detector **480**, an enclosed detector **460**, or a combination thereof, connected to the controller **415** (also referred to as a processor herein). The controller **415** may adjust an amount of power delivered by the driver circuit **424** in response to presence signals from the presence detector **480** and the enclosed detector **460**. The transmitter **404** may receive power through a number of power sources, such as, for example, an AC-DC converter (not shown) to convert conventional AC power present in a building, a DC-DC converter (not shown) to convert a conventional DC power source to a voltage suitable for the transmitter **404**, or directly from a conventional DC power source (not shown).

As a non-limiting example, the presence detector **480** may be a motion detector utilized to sense the initial presence of a device to be charged that is inserted into the coverage area of the transmitter **404**. After detection, the transmitter **404** may be turned on and the RF power received by the device may be used to toggle a switch on the Rx device in a pre-determined manner, which in turn results in changes to the driving point impedance of the transmitter **404**.

As another non-limiting example, the presence detector **480** may be a detector capable of detecting a human, for example, by infrared detection, motion detection, or other suitable means. In some exemplary embodiments, there may be regulations limiting the amount of power that a transmit coil **414** may transmit at a specific frequency. In some cases, these regulations are meant to protect humans from electromagnetic radiation. However, there may be environments where a transmit coil **414** is placed in areas not occupied by humans, or occupied infrequently by humans, such as, for example, garages, factory floors, shops, and the like. If these environments are free from humans, it may be permissible to increase the power output of the transmit coil **414** above the normal power restrictions regulations. In other words, the controller **415** may adjust the power output of the transmit coil **414** to a regulatory level or lower in response to human presence and adjust the power output of the transmit coil **414** to a level above the regulatory level when a human is outside a regulatory distance from the electromagnetic field of the transmit coil **414**.

As a non-limiting example, the enclosed detector **460** (may also be referred to herein as an enclosed compartment detector or an enclosed space detector) may be a device such as a sense switch for determining when an enclosure is in a closed or open state. When a transmitter is in an enclosure that is in an enclosed state, a power level of the transmitter may be increased.

In exemplary embodiments, a method by which the transmitter **404** does not remain on indefinitely may be used. In this case, the transmitter **404** may be programmed to shut off after a user-determined amount of time. This feature prevents the transmitter **404**, notably the driver circuit **424**, from running long after the wireless devices in its perimeter are fully charged. This event may be due to the failure of the circuit to detect the signal sent from either the repeater or the receive coil that a device is fully charged. To prevent the transmitter **404** from automatically shutting down if another device is placed in its perimeter, the transmitter **404** automatic shut off feature may be activated only after a set period of lack of motion detected in its perimeter. The user may be able to determine the inactivity time interval, and change it as desired. As a non-limiting example, the time interval may be longer than that needed to fully charge a specific type of wireless device under the assumption of the device being initially fully discharged.

FIG. **5** is a functional block diagram of a receiver **508** that may be used in the wireless power transfer system of FIG. **1**, in accordance with exemplary embodiments of the invention. The receiver **508** includes receive circuitry **510** that may include a receive coil **518**. Receiver **508** further couples to device **550** for providing received power thereto. It should be noted that receiver **508** is illustrated as being external to device **550** but may be integrated into device **550**. Energy may be propagated wirelessly to receive coil **518** and then coupled through the rest of the receive circuitry **510** to device **550**. By way of example, the charging device may include devices such as mobile phones, portable music players, laptop computers, tablet computers, computer peripheral devices, communication devices (e.g., Bluetooth devices), digital cameras, hearing aids (an other medical devices), and the like.

Receive coil **518** may be tuned to resonate at the same frequency, or within a specified range of frequencies, as transmit coil **414** (FIG. **4**). Receive coil **518** may be similarly dimensioned with transmit coil **414** or may be differently sized based upon the dimensions of the associated device **550**.

By way of example, device **550** may be a portable electronic device having diametric or length dimension smaller that the diameter of length of transmit coil **414**. In such an example, receive coil **518** may be implemented as a multi-turn coil in order to reduce the capacitance value of a tuning capacitor (not shown) and increase the receive coil's impedance. By way of example, receive coil **518** may be placed around the substantial circumference of device **550** in order to maximize the coil diameter and reduce the number of loop turns (i.e., windings) of the receive coil **518** and the inter-winding capacitance.

Receive circuitry **510** may provide an impedance match to the receive coil **518**. Receive circuitry **510** includes power conversion circuitry **506** for converting a received RF energy source into charging power for use by the device **550**. Power conversion circuitry **506** includes an RF-to-DC converter **520** and may also in include a DC-to-DC converter **522**. RF-to-DC converter **520** rectifies the RF energy signal received at receive coil **518** into a non-alternating power with an output voltage represented by V_{rect}. The DC-to-DC converter **522** (or other power regulator) converts the rectified RF energy signal into an energy potential (e.g., voltage) that is compatible with device **550** with an output voltage and output current represented by V_{out} and I_{out}. Various RF-to-DC converters are contemplated, including partial and full rectifiers, regulators, bridges, doublers, as well as linear and switching converters.

Receive circuitry **510** may further include switching circuitry **512** for connecting receive coil **518** to the power conversion circuitry **506** or alternatively for disconnecting the power conversion circuitry **506**. Disconnecting receive coil **518** from power conversion circuitry **506** not only suspends charging of device **550**, but also changes the "load" as "seen" by the transmitter **404** (FIG. **2**).

As disclosed above, transmitter **404** includes load sensing circuit **416** that may detect fluctuations in the bias current provided to transmitter driver circuit **424**. Accordingly, transmitter **404** has a mechanism for determining when receivers are present in the transmitter's near-field.

When multiple receivers **508** are present in a transmitter's near-field, it may be desirable to time-multiplex the loading and unloading of one or more receivers to enable other receivers to more efficiently couple to the transmitter. A receiver **508** may also be cloaked in order to eliminate coupling to other nearby receivers or to reduce loading on nearby transmitters. This "unloading" of a receiver is also known herein as a "cloaking" Furthermore, this switching between unloading and loading controlled by receiver **508** and detected by transmitter **404** may provide a communication mechanism from receiver **508** to transmitter **404** as is explained more fully below. Additionally, a protocol may be associated with the switching that enables the sending of a message from receiver **508** to transmitter **404**. By way of example, a switching speed may be on the order of 100 μsec.

In an exemplary embodiment, communication between the transmitter **404** and the receiver **508** refers to a device sensing and charging control mechanism, rather than conventional two-way communication (i.e., in band signaling using the coupling field). In other words, the transmitter **404** may use on/off keying of the transmitted signal to adjust whether energy is available in the near-field. The receiver may interpret these changes in energy as a message from the transmitter **404**. From the receiver side, the receiver **508** may use tuning and de-tuning of the receive coil **518** to adjust how much power is being accepted from the field. In some cases, the tuning and de-tuning may be accomplished via the switching circuitry **512**. The transmitter **404** may detect this difference in power used from the field and interpret these changes as a message from the receiver **508**. It is noted that other forms of modulation of the transmit power and the load behavior may be utilized.

Receive circuitry **510** may further include signaling detector and beacon circuitry **514** used to identify received energy fluctuations, that may correspond to informational signaling from the transmitter to the receiver. Furthermore, signaling and beacon circuitry **514** may also be used to detect the transmission of a reduced RF signal energy (i.e., a beacon signal) and to rectify the reduced RF signal energy into a nominal power for awakening either un-powered or power-depleted circuits within receive circuitry **510** in order to configure receive circuitry **510** for wireless charging.

Receive circuitry **510** further includes processor **516** for coordinating the processes of receiver **508** described herein including the control of switching circuitry **512** described herein. Cloaking of receiver **508** may also occur upon the occurrence of other events including detection of an external wired charging source (e.g., wall/USB power) providing charging power to device **550**. Processor **516**, in addition to controlling the cloaking of the receiver, may also monitor beacon circuitry **514** to determine a beacon state and extract messages sent from the transmitter **404**. Processor **516** may also adjust the DC-to-DC converter **522** for improved performance.

FIG. **6** depicts a schematic diagram of an exemplary single switching device differential drive amplifier **624** according to some aspects. In certain aspects, the differential drive amplifier **624** can correspond to the driver circuit **224** of FIG. **2**. The amplifier **624** includes an upper RLC (resistor/inductor/capacitor) network **670** connected to a supply voltage (+Vcc), and a lower RLC network **672** connected to ground. The upper network **670** and the lower network **672** share a switching device **671**, which floats between the two networks. The switching device **671** may receive a control or drive signal that may control the switching operations of the switching device **671**. The switching device **671** may also define two output nodes n**1** and n**2**, where differential output signals are respectively present. The control or drive signal may cause the switching device to alter its conductive state. In this manner, differential output signals may be produced at node n**1** and node n**2** that are substantially equal and opposite with respect to each other.

The upper RLC network **670** may be matched with the lower RLC network **672**, such that the characteristics (e.g., resistances, capacitances, inductances, and the like) of the components of the networks are substantially identical. According to some example embodiments, the switching device **671** may be connected between inductors (also referred to as windings or coils) L**1** and L**2**, which may be matched and tightly coupled. The inductors L**3** and L**4** may also be matched and tightly coupled.

As used herein, the term “float” may be used to indicate that a device is not connected to a fixed potential (e.g., +Vcc or ground). For example, a device may be floating if it is connected through non-zero impedance components, such as inductors or capacitors to a fixed potential. As such, the potential at a terminal of a floating component may tend to wander or float with respect to a fixed potential.

The switching device **671**, which may be embodied as a transistor (e.g., a field effect transistor or the like), may switch open or closed in response to a control or drive signal, such as the square wave depicted in FIG. **6**. According to various example embodiments, the currents I**1** and I**2** in the upper and lower networks are in opposite directions in the respective networks. As result of the switching operations performed by the switching device **671** and currents I**1** and I**2**, differential output signals may be generated at nodes n**1** and n**2**. Due to the coupling effect of the L**3** inductor with the L**4** inductor, the differential output signals generated at nodes n**1** and n**2** may interact to eliminate noise present in the input signal. As such, the load RL may receive a signal having an associated reduction in both conducted and radiated noise.

As stated above, the coupling between inductors L**3** and L**4**, may facilitate the reduction in noise provided by the amplifier. To maximize noise cancellation, inductors L**3** and L**4** may be positioned as close together as possible so that the inductors are strongly coupled. In practice, a designer may desire to come as close to the hypothetical case of complete noise cancellation, while still avoiding the perfect cancellation of signals. According to some example embodiments, a pair of strongly coupled inductors may be used that are combined in a single package, such as the Coiltronix DRQ127-470-R, which results in the inductors being as closely coupled as possible. As a result of the strong coupling, the current in each of the inductors may be forced to be almost equivalent in value, facilitating the generation of the inversely oriented signals. According to example embodiments where the inductors are not included in the same package (e.g., a wireless power system), the inductors L**3** and L**4** may be interwounded coils used for transmitting wireless power to one or more secondary coils and may utilize strong coupling by maintaining the inductors in close proximity.

FIG. **7** illustrates a drive circuit **722** in accordance with some example embodiments. In certain aspects, the driver circuit **722** can correspond to the oscillator **222** of FIG. **2**. The drive circuit **722** may receive an input signal at **781** and provide a drive signal at **784** to the gate of the switching device **771**. The drive signal at **784** may be generated via a gate drive transformer **782** and an h-bridge network **783**. According to some example embodiments, to generate the drive signal at **784** for a switching device, an isolated drive scheme may be implemented using the transformer **782**. According to some example embodiments, the transformer **782** may be a pulse transformer. The transformer **782** may sense the voltage difference across its input terminals and apply the same voltage across its output terminals. By connecting the output terminals of the transformer **782** across the gate and source of the switching device **771**, switching may be performed even though the source and the drain are floating between n**1** and n**2**.

In some example embodiments, the switching device **771** may be designed to switch at a rapid speed, which may require a rapidly changing drive signal at the gate of the switching device. To achieve the rapidly changing drive signal, the h-bridge circuit **783** may be utilized. Referring to FIG. **6**, the h-bridge circuit **783** may include diodes, D**1** and D**2**, and bipolar junction transistors (BJTs), B**1** and B**2**. The diodes and the capacitors, C**1** and C**2**, may form a voltage doubler circuit, which may be used to generate a direct current (DC) voltage across nodes n**4** and n**2**. The BJTs may be set in a push-pull configuration to drive the gate of switching device **771** using this DC voltage. A push-pull configuration may rely on several inherent characteristics of BJTs. B**1** may be a PNP transistor and act as a closed switch between the collector (connected to node n**4**) and emitter (connected to node ng), while the BJTs base voltage (connected to node n**3**) may be higher than the voltage at the emitter. On the other hand, B**2** may be an NPN transistor and act as a closed switch between its collector (connected to node n**2**) and emitter (connected to node ng) while its base voltage (connected to node n**3**) may be lower than the voltage at the emitter. When not operating as a closed switch both B**1** and B**2** may act as open switches.

When the transformer forces node n**3**'s voltage higher than the voltage at node n**2**, B**1** may sense a positive voltage between its base and emitter terminals resulting in current flowing from the capacitor C**1** to the gate of switching device **771**. Likewise, B**2** may sense the lower voltage between its base and its emitter causing the gate of switching device **71** to discharge to node n**2**. As a result, the h-bridge **783** provides for fast ramp up and ramp down of the voltage of the signal at the gate of switching device **771** (with respect to the source) thereby allowing for rapid switching.

FIG. **8** depicts an example wireless power system **800** in accordance with various aspects. The wireless power system of FIG. **8** may include a wireless power transmitter **804** and a wireless power receiver **808**. The wireless power transmitter **804** may include a differential drive amplifier **824**, which, in turn, may include a single switching device **871** and a drive circuit **822**. In certain aspects, the drive circuit **822** and the differential drive amplifier **824** may correspond to the driver circuit **722** and the differential drive amplifier **624** of FIGS. **6** and **7**, respectively. The drive circuit **822** may receive an input signal **802**. The wireless power transmitter **804** may also include a supply network **825** and primary coils **814**. The wireless power receiver **808** may include secondary coils **818**, a rectifier **834**, and a load **850**, which may be a dynamic load. In some example embodiments, the load **850** may be rechargeable battery for an electronic device.

According to various aspects, the wireless power system of FIG. **8** implements switching operations to convert a DC voltage provided by the supply network **825** into a high frequency signal. The differential drive amplifier **824** may operate, as described above, to generate two high frequency output signals that are differential and substantially equal and opposite. The differential output signals may be delivered to respective primary coils that are positioned to provide for noise cancellation through a coupling of the primary coils **814**. The primary coils **814** may be oriented such that the currents in the coils flow in the same direction, thereby providing for noise cancellation while also having a minimal effect on the magnetic field generation of the primary coils **814**. Due to the direction of the current, magnetic fields may be generated that have the same polarity. The magnetic field may induce a current in the one or more secondary coils of the wireless power receiver **818**. The one or more secondary coils **818** may receive an induced alternating current (AC) signal, which may then be rectified, via the rectifier **834**, and fed to a load **850**.

According to some aspects, the primary coils **814** may be configured to facilitate noise cancellation by co-locating substantially equal and opposite voltages at any location on a planar surface defined by the primary coils **814**. According to some example embodiments, the primary coils **814** may be configured to co-locate substantially equal and opposite voltages at any location in a three-dimensional space surrounding the primary coil network. According to various example embodiments the primary coils **814** may be driven by differential output signals as described above. However, according to some example embodiments, the primary coil arrangements and configurations described herein may be utilized in conjunction with any type of differential drive amplifier, including but not limited to a single switching device differential drive amplifier as described herein. For example, the primary coil arrangements and configurations may be used with a differential drive amplifier that includes multiple switching devices and/or transistors.

With respect to the positional configuration of the primary coils **814**, each primary coil may be wound as a spiral on a geometric plane. To facilitate co-location of voltages, the distance between each turn of a coil may be increased as the spiral configuration moves towards the center of an area. The first coil and the second coil may therefore have a spiral configuration substantially within a common plane that provides for co-location of substantially equal and opposite voltages within the first and second coils, respectively, at any location on the common plane. According to some example embodiments, a single coil may be utilized that spirals into a center point or area, and then spirals back out. As such, a coil arrangement may be constructed of two coils that are connected at a central location to achieve a single coil embodiment.

FIG. **9** illustrates a perspective view of an exemplary two coil arrangement according to various aspects. FIG. **10** illustrates a top view of an exemplary two coil arrangement according to various example aspects. FIG. **11** illustrates a top view of the aspect of FIG. **10** with only a first coil depicted, and FIG. **12** illustrates a top view of the aspect of FIG. **10** with only a second coil depicted.

In some aspects, the primary coils **814** of FIG. **8** may be formed as the two coil structures of FIGS. **9** and **10**. Each coil may be driven by a signal that is substantially equal and opposite relative to a signal driving the other coil. One coil may be wound counterclockwise while the other coil may be wound clockwise. One coil may be substantially a reflection of the other coil and have a same total length as the other coil. The two coils may be configured together to create a single coil structure by placing one coil above, below, or interwove the other coil. The two coil arrangements of FIGS. **9** and **10**, for instance, may form a single coil structure where the coils are located substantially on a common plane and have a common center. In some aspects, a single coil structure may instead include one coil or three or more coils. In certain aspects, the single coil structure may further be used as a receiver coil such as secondary coils **818** of FIG. **8**.

A single coil structure may be non-planar in some aspects and planar with a flexible plane in other aspects. The single coil structure may be any symmetric shape, including rectangle or circle, for example. The single coil structure may be oriented in various orientations including vertical, horizontal, and diagonally, among other possibilities. Further, the single coil structure may be located on or in a variety of items including surfaces, walls, tape, and portable electronics, among other possibilities.

In some aspects, the portion of a single coil structure used to input in the signal to each coil may feed in from a location other than a corner along the edge of the single coil structure. For example, the signal may be input perpendicular to the top side of the single coil structure along a top-center edge as illustrated in FIG. **10**.

Each corner of a single coil structure may have a minimum turn radius. In particular aspects, the minimum turn radius may be approximately 5 millimeters. The minimum turn radius may be greater or less in other aspects.

A receive coil, such as secondary coils **818** of FIG. **8**, may be placed above or below a perimeter or inside area of the single coil structure. The receive coil may be a first distance from one coil of the single coil structure and a second distance from another coil of the single coil structure. In some aspects, the first and second distances may each be between a range of between 3 millimeters to 40 millimeters. In other aspects, the first and second distances may be less than 3 millimeters or greater than 40 millimeters. In addition, in some aspects, the first distance may equal the second distance so that the first and second coils of the single coil structure may be closely located and substantially located on a common plane.

FIG. **13** illustrates a side view of an example cross section **1300** of a single coil structure from a center **1302** to an outermost turn **1312** (i.e., the fifth turn) of the single coil structure. The spacings between consecutive turns of the single coil structure may be represented as variables and determined as a function of distance along the cross section of the single coil structure from the center **1302** to the outermost turn **1312**. The illustrated single coil structure includes N turns (i.e., five turns), including a first turn **1304**, second turn **1306**, third turn **1308**, fourth turn **1310**, and outermost turn **1312**. The distance from the center **1302** to an i-th turn (e.g., the third turn) is denoted as d_i, and the distance from the center **1302** to the center of the outermost turn **1312** is denoted as D/2.

In some aspects, the distance d_i along a cross section from the center of a single coil structure to an i-th turn is given by the function of Equation 1.

$$d_i = \frac{D}{2} \cdot \frac{1 - r^{i-1}}{1 - r^{N-1}} \qquad \text{Equation 1}$$

where

$$\frac{D}{2}$$

is a distance from the center to the outermost turn, r is a value corresponding to spacings between turns of the single spiral structure, N is a sum of a total number of turns of the single spiral structure, and i is a number corresponding to the particular turn. In some aspects, Equation 1 additionally or alternatively describes a distance along a cross section from the center of one turn of a single coil structure to an i-th turn. Further, in some aspects, a distance along a cross section from the center of a single coil structure or the center of one turn of the single coil structure to an i-th turn is additionally or alternatively given by a function where the distance is proportional to D and i and inversely proportional to N.

As an example cross section line, FIG. **10** illustrates a top view of a cross section line drawn on a single coil structure. As illustrated, each coil of the single coil structure may share a common cross section line that is substantially located on a common plane. The cross section line alternately crosses six turns of the two-coil single coil structure, crossing three turns of each of the two coils. The spacings, such as spacings S_1, S_2, S_3, between consecutive turns generally increase from an outermost turn to the center of the single coil structure.

FIG. **14** is a plot **1400** of normalized mutual inductance versus position for an example single coil structure. The mutual inductance values **1402** in plot **1400** show the mutual inductance for a cross section **1404** of a single coil structure relative to a receive coil at positions 10 millimeters above the cross section. The mutual inductance values **1402** are normalized by a maximum mutual inductance of the positions along the cross section. The receive coil used to construct the plot **1400** was a one turn coil having finite width of 44 millimeters where the field across the receive coil was averaged to determine a mutual inductance distribution. In addition, along the position axis, an illustrative side view of the cross section **1404** for each turn of the single coil structure is shown as multiple Os, providing a sense of the turns and spacings that resulted in the illustrated mutual inductance distribution.

Similarly, FIG. **15** is a plot **1500** of normalized mutual inductance versus position for an example single coil structure. The mutual inductance values **1502** in plot **1500** show the mutual inductance for a cross section **1504** of a single coil structure relative to a receive coil at positions 10 millimeters above the cross section. The mutual inductance values **1502** are normalized by a maximum mutual inductance of the positions along the cross section. The receive coil used to construct the plot **1500** was a one turn coil having finite width of 44 millimeters where the field across the receive coil was averaged to determine a mutual inductance distribution. In addition, along the position axis, an illustrative side view of the cross section **1504** for each turn of the single coil structure is shown as multiple Os, providing a sense of the turns and spacings that resulted in the illustrated mutual inductance distribution.

By comparing the distributions of FIGS. **14** and **15**, it can be noted that varying spacings between turns of a single coil structure results in variation between a maximum and minimum normalized mutual inductance of the distribution. Advantageously, less variation between the maximum and minimum normalized mutual inductance corresponds to increased uniformity in the magnetic field generated by the cross section of the single coil structure. As a result, spacings between turns of a single coil structure may be designed so that the minimum normalized mutual inductance exceeds a percentage of the maximum normalized mutual inductance along some or all cross sections of a primary coil structure. For instance, the spacings between turns may be selected so that a minimum normalized mutual inductance exceeds 50% or 65% of a maximum normalized mutual inductance along some or all cross sections of a single coil structure. Other minimum mutual inductance thresholds may be used in some aspects. Further, advantageously, in certain aspects, by applying minimum mutual inductance thresholds to various cross sections of a single coil structure, the single coil structure is formed to create a substantially uniform three-dimensional magnetic field at a distance above or below the single coil structure.

In some aspects, spacings between turns may be designed so that variation between the maximum and minimum normalized mutual inductance is substantially minimized. For example, the value of r in Equation 1 may be solved or selected so that portions of the single coil structure along a cross section have a difference between a maximum and minimum normalized mutual inductance that varies less than for other values of r. In one aspect, the value of r may be in the range of around 0.65 to 0.68 since a value of approximately 0.67 may result in a minimum difference between the maximum and minimum normalized mutual inductance. When the value of r is approximately 0.67, a percentage difference between the maximum and minimum normalized mutual inductance along the cross section may be as low as approximately 21%.

The spacings between turns of a single coil structure may generally increase from an outermost turn to the center of the single coil structure. Such an increase in the spacings may enable generation of a substantially uniform magnetic field distribution above or below the single coil structure. Advantageously, in certain aspects, the substantially uniform magnetic field may be constructed without use of a parasitic loop, reducing losses due to added resistance from the parasitic loop. The distance from the single coil structure to where the substantially uniform magnetic field is strongest may be approximately 3 millimeters to 40 millimeters above or below the single coil structure in some aspects. Further, the single coil structure may be sized to produce a magnetic field sufficiently large to simultaneously charge more than one mobile phone. Given the exemplary aspects discussed in this disclosure, the uniform magnetic field may also permit devices to wirelessly receive power even above the outer edges of the primary coil structure.

The spacings between consecutive turns of a single coil structure may be designed to increase from an outermost turn to the center of the single coil structure, in part, so that alternating current resistances at high frequencies may be diminished. In certain aspects, such a design may be effective for decreasing resistance and corresponding energy losses at operating frequencies of about 6.78 MHz.

Information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

The various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. The described functionality may be implemented in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the embodiments of the invention.

The various illustrative blocks, modules, and circuits described in connection with the embodiments disclosed herein may be implemented or performed with a general purpose processor, a Digital Signal Processor (DSP), an Application Specific Integrated Circuit (ASIC), a Field Programmable Gate Array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

The steps of a method or algorithm and functions described in connection with the embodiments disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a tangible, non-transitory computer-readable medium. A software module may reside in Random Access Memory (RAM), flash memory, Read Only Memory (ROM), Electrically Programmable ROM (EPROM), Electrically Erasable Programmable ROM (EEPROM), registers, hard disk, a removable disk, a CD ROM, or any other form of storage medium known in the art. A storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and blu ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer readable media. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a user terminal. In the alternative, the processor and the storage medium may reside as discrete components in a user terminal.

For purposes of summarizing the disclosure, certain aspects, advantages and novel features of the inventions have been described herein. It is to be understood that not necessarily all such advantages may be achieved in accordance with any particular embodiment of the invention. Thus, the invention may be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other advantages as may be taught or suggested herein.

Various modifications of the above described embodiments will be readily apparent, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the invention. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

What is claimed is:

1. A transmission coil for transmitting wireless power to a receive coil, the transmission coil comprising:

a first spiral coil comprising a plurality of turns, a center of the first spiral coil to an outermost turn of the first spiral coil defining a first cross section; and

a second spiral coil comprising a plurality of turns, a center of the second spiral coil to an outermost turn of the second spiral coil defining a second cross section, portions of the first spiral coil along the first cross section and the second spiral coil along the second cross section having a mutual inductance with respect to the receive coil greater than 65% of a maximum mutual inductance along the first and second cross sections, the second spiral coil counter-wound relative to the first spiral coil.

2. The transmission coil of claim **1**, wherein the second spiral coil is located above or below the first spiral coil.

3. The transmission coil of claim **1**, wherein the second spiral coil is interwoven with the first spiral coil.

4. The transmission coil of claim **1**, wherein a total length of the second spiral coil is a same length as a total length of the first spiral coil, and the second spiral coil is substantially shaped as a reflection of the first spiral coil.

5. The transmission coil of claim **1**, wherein the receive coil comprises a first receive coil and a second receive coil.

6. The transmission coil of claim **1**, wherein the second spiral coil is located substantially on a common plane with the first spiral coil and has a common center with first spiral coil,

the first and second cross sections are located substantially on the common plane, and

a turn distance from the common center to a center of a particular turn along the first or second cross section of the first or second spiral coil is a function of a distance from the common center to the outermost turn of the first or second spiral coil, a first value corresponding to spacings between turns of the first or second spiral coil, a sum of a total number of turns of the first and second spiral coils, and a first number corresponding to the particular turn.

7. The transmission coil of claim **1**, wherein the first and second spiral coil are electrically coupled to a driver circuit and configured to wirelessly transmit power at a level sufficient to charge or power a receiver device.

8. The transmission coil of claim **1**, wherein input signals for first and second spiral coil are configured to be within a frequency range of 6.5 Megahertz to 7 Megahertz.

9. The transmission coil of claim **1**, wherein each turn of the first and second spiral coil is configured to have a turn radius greater than a minimum turn radius of 5 millimeters.

10. A method for transmitting wireless power to a receive coil, the method comprising:

driving with electrical current a first spiral coil comprising a plurality of turns, a center of the first spiral coil to an outermost turn of the first spiral coil defining a first cross section; and

driving with electrical current a second spiral coil comprising a plurality of turns, a center of the second spiral coil to an outermost turn of the second spiral coil defining a second cross section, portions of the first spiral coil along the first cross section and the second spiral coil along the second cross section having a mutual inductance with respect to the receive coil greater than 65% of a maximum mutual inductance along the first and second cross sections, the second spiral coil counter-wound relative to the first spiral coil.

11. The method of claim **10**, wherein the second spiral coil is located above or below the first spiral coil.

12. The method of claim **10**, wherein the second spiral coil is interwoven with the first spiral coil.

13. The method of claim **10**, wherein a total length of the second spiral coil is a same length as a total length of the first spiral coil, and the second spiral coil is substantially shaped as a reflection of the first spiral coil.

14. The method of claim **10**, wherein the receive coil comprises a first receive coil and a second receive coil.

15. The method of claim **10**, wherein the second spiral coil is located substantially on a common plane with the first spiral coil and has a common center with first spiral coil,

the first and second cross sections are located substantially on the common plane, and

a turn distance from the common center to a center of a particular turn along the first or second cross section of the first or second spiral coil is a function of a distance from the common center to the outermost turn of the first or second spiral coil, a first value corresponding to spacings between turns of the first or second spiral coil, a sum of a total number of turns of the first and second spiral coils, and a first number corresponding to the particular turn.

16. The method of claim **10**, wherein the first and second spiral coil are electrically coupled to a driver circuit and configured to wirelessly transmit power at a level sufficient to charge or power a receiver device.

17. The method of claim **10**, wherein input signals for first and second spiral coil are configured to be within a frequency range of 6.5 Megahertz to 7 Megahertz.

18. The method of claim **10**, wherein each turn of the first and second spiral coil is configured to have a turn radius greater than a minimum turn radius of 5 millimeters.

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