

(12) **United States Patent**
Aldhafer et al.

(10) **Patent No.:** **US 12,388,300 B2**
(45) **Date of Patent:** **Aug. 12, 2025**

(54) **ALIGNMENT DEVICE FOR ALIGNING TRANSMITTER AND RECEIVER OF WIRELESS POWER TRANSFER SYSTEM, AND METHOD THEREFOR**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **18/341,392**

(22) Filed: **Jun. 26, 2023**

(65) **Prior Publication Data**

US 2023/0336038 A1 Oct. 19, 2023

Related U.S. Application Data

(63) Continuation of application No. 17/083,735, filed on Oct. 29, 2020, now Pat. No. 11,728,695.

(60) Provisional application No. 62/927,224, filed on Oct. 29, 2019.

(51) **Int. Cl.**

H02J 50/90 (2016.01)

H02J 50/12 (2016.01)

H02J 50/80 (2016.01)

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

CPC **H02J 50/90** (2016.02); **H02J 50/12** (2016.02); **H02J 50/80** (2016.02)

(58) **Field of Classification Search**

CPC H02J 50/90; H02J 50/80; H02J 50/12

USPC 307/104

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

9,409,490 B2 *	8/2016	Kawashima	.....	H02J 7/00034
11,728,695 B2 *	8/2023	Aldhafer	.....	H02J 50/90
				307/104
2011/0084652 A1 *	4/2011	Julstrom	.....	H02J 50/12
				320/108
2013/0021168 A1 *	1/2013	Jones	.....	G01R 33/00
				324/226
2013/0024059 A1 *	1/2013	Miller	.....	H02J 7/00034
				320/108
2014/0015328 A1 *	1/2014	Beaver	.....	H02J 7/34
				307/104
2014/0132210 A1 *	5/2014	Partovi	.....	H02J 50/12
				320/108
2015/0022142 A1	1/2015	Garcia Briz et al.		
2015/0077046 A1	3/2015	Huang et al.		
2015/0094887 A1 *	4/2015	Kawashima	.....	B60L 53/36
				320/108
2015/0202970 A1 *	7/2015	Huang	.....	B60L 53/126
				320/108
2015/0255205 A1	9/2015	Islinger		
		(Continued)		

OTHER PUBLICATIONS

International Search Report and Written Opinion for PCT/CA2020/051456 mailed Jan. 15, 2021.

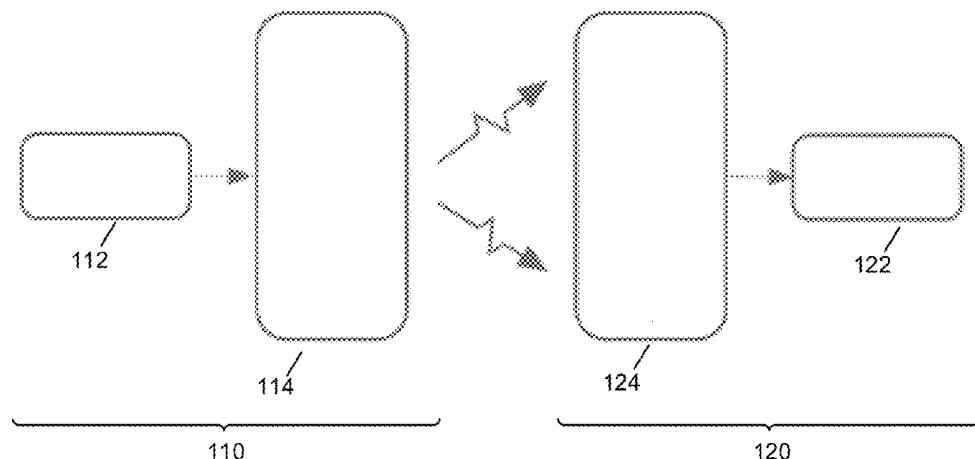
Primary Examiner — Alfonso Perez Borroto

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(57) **ABSTRACT**

An alignment device comprises a coil configured to generate an induced voltage from a magnetic field, or an electrode configured to generate an induced voltage from an electric field. The alignment device further comprises a comparator configured to compare the induced voltage to a threshold voltage and activate an indicator based on the comparison.

17 Claims, 17 Drawing Sheets



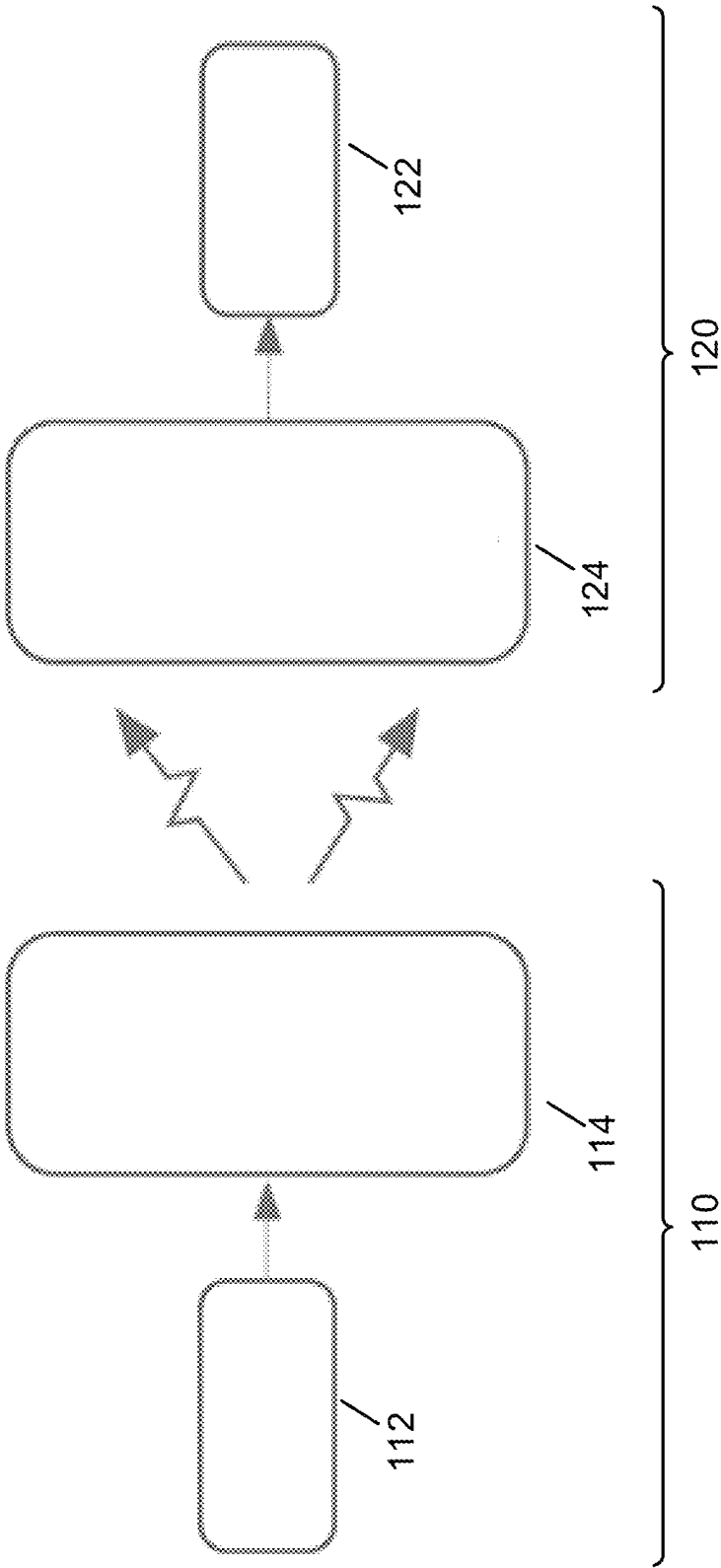
(56)

References Cited

U.S. PATENT DOCUMENTS

2015/0323694	A1 *	11/2015	Roy	H02J 50/70 307/104
2016/0218520	A1 *	7/2016	Mehas	H02J 50/90
2016/0226298	A1	8/2016	Shimokawa et al.	
2017/0018951	A1	1/2017	Park	
2019/0118657	A1 *	4/2019	Wang	B60L 53/39

* cited by examiner



100

Figure 1

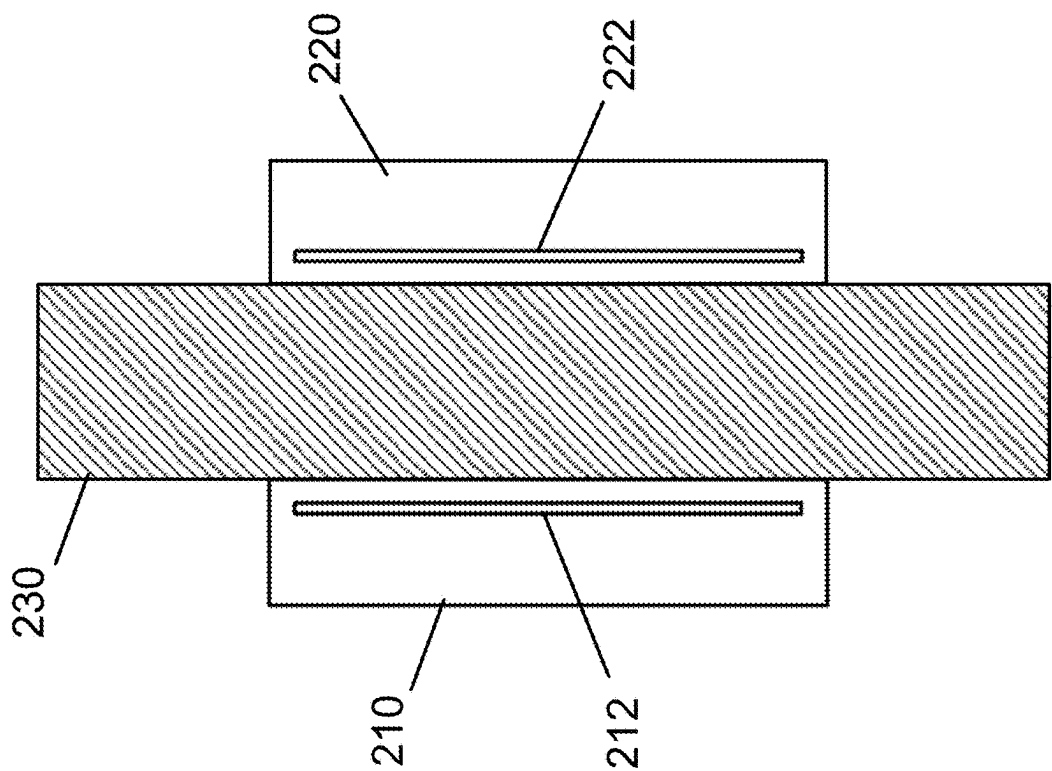


Figure 2

200

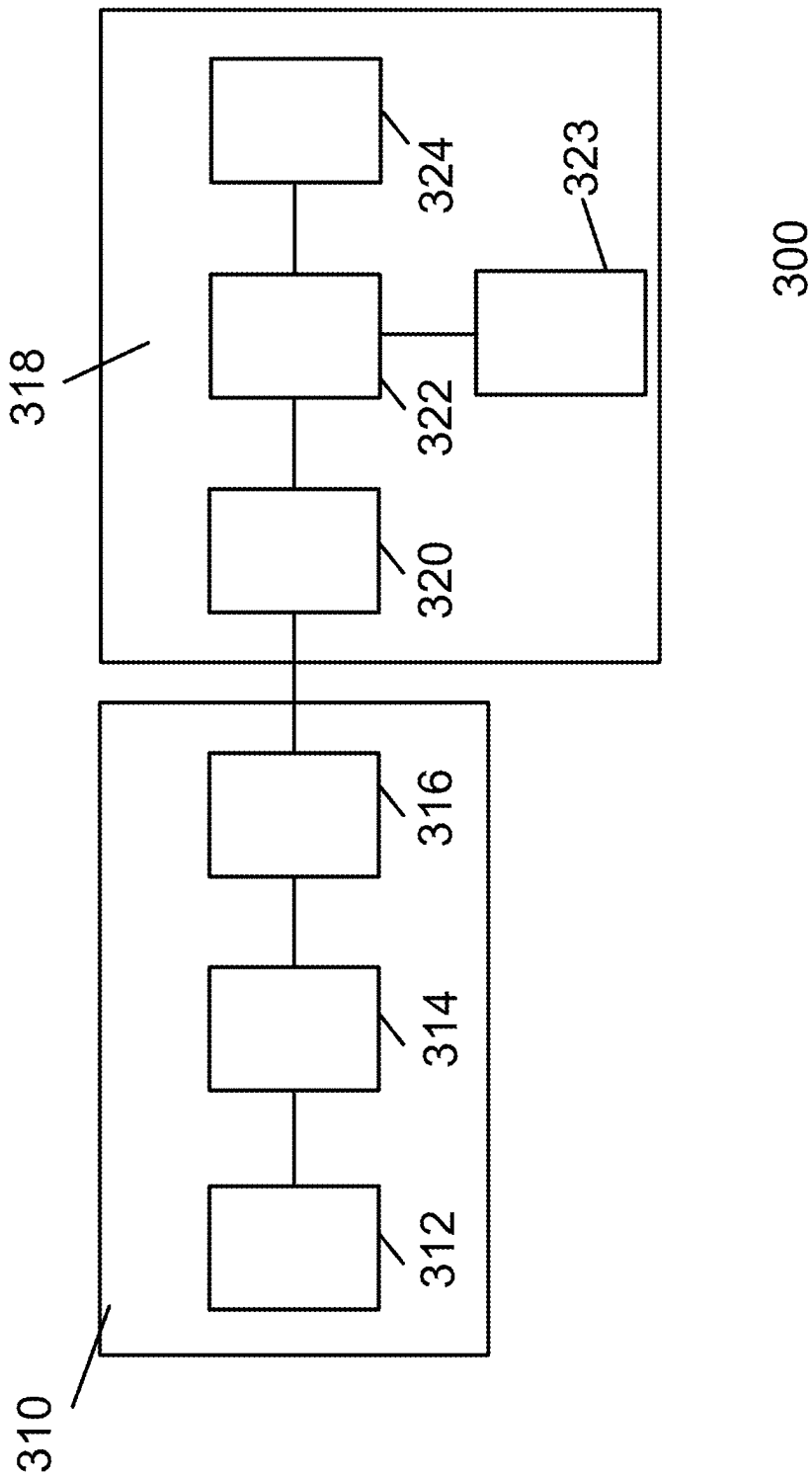


Figure 3

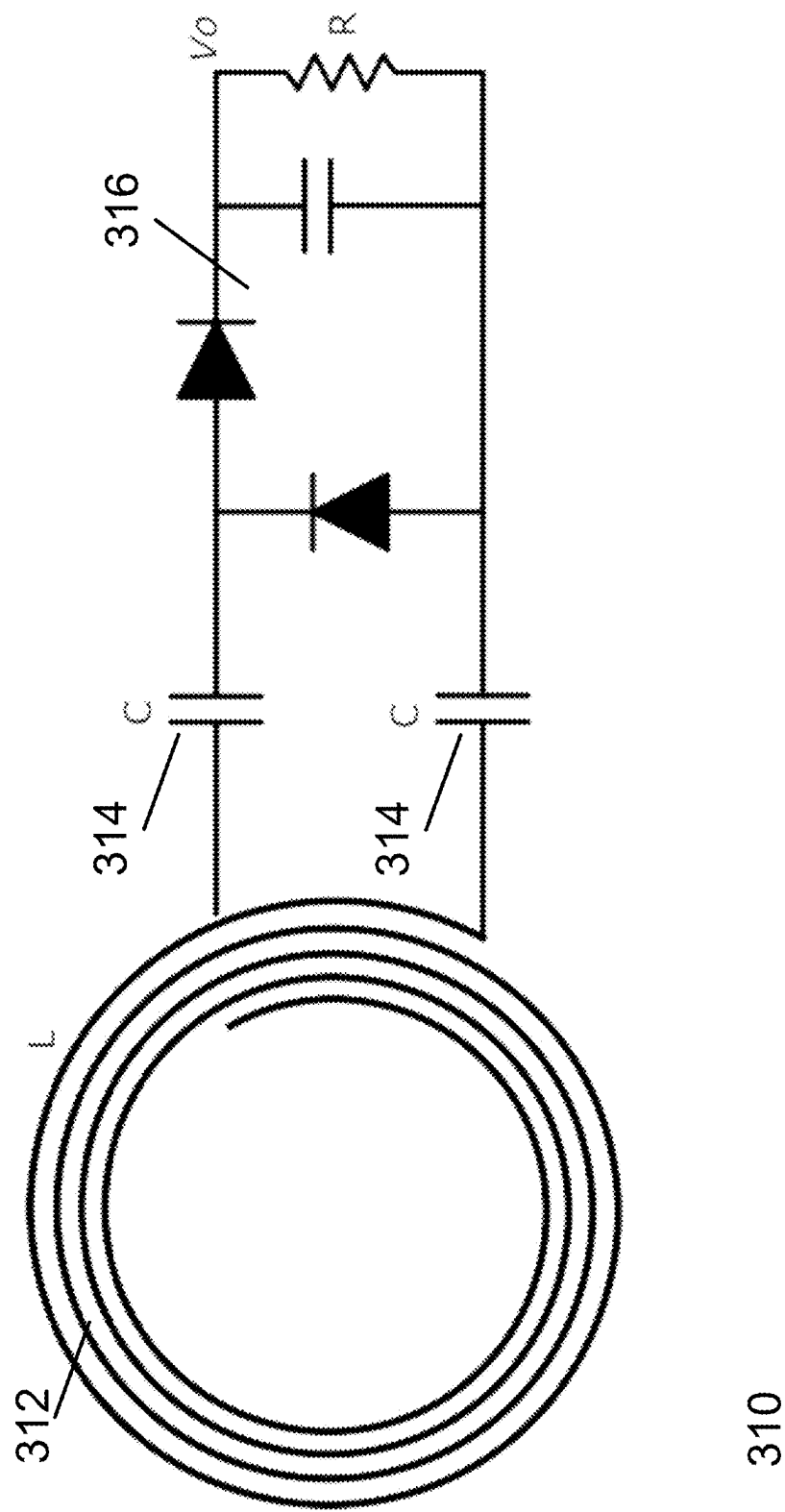


Figure 4

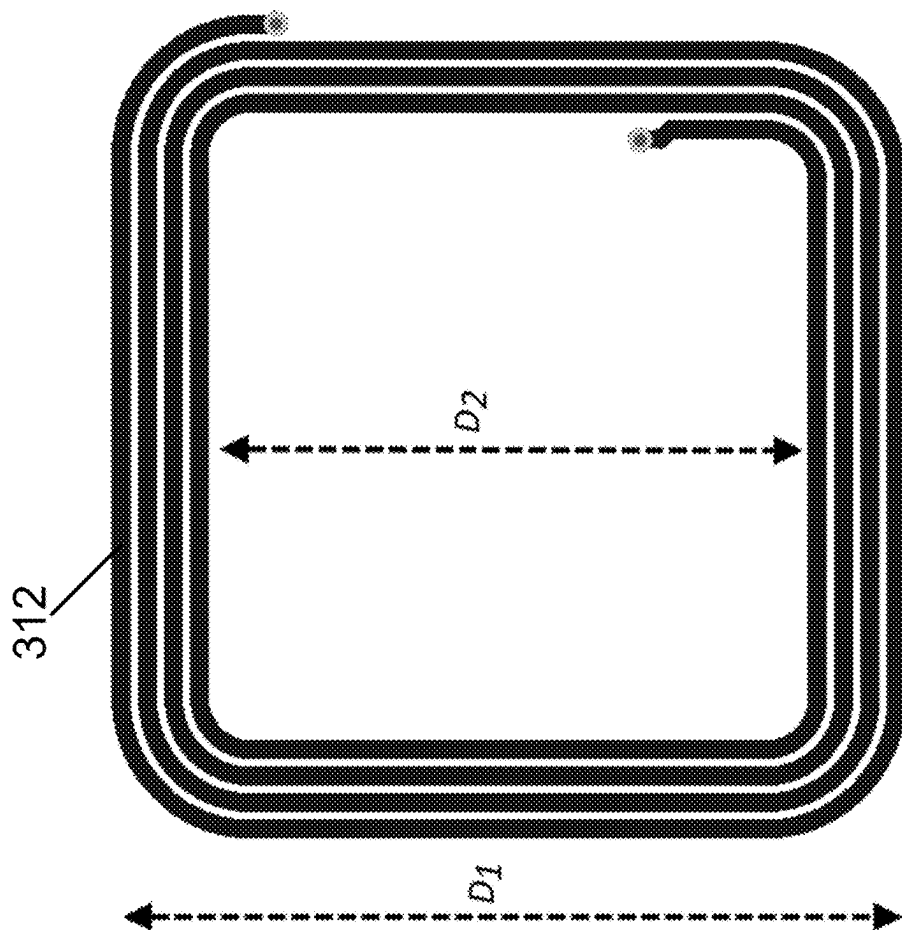


Figure 5

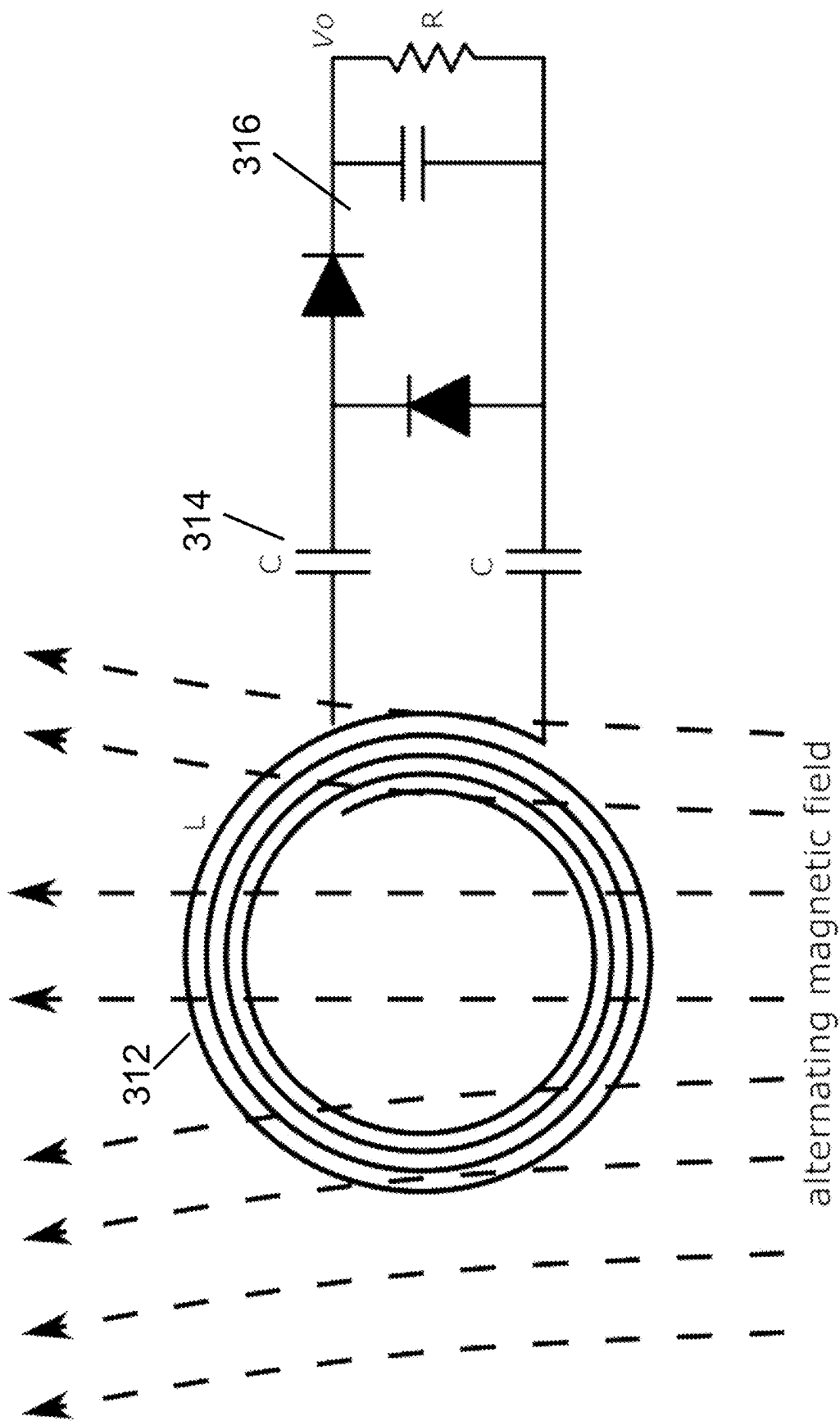


FIG. 6

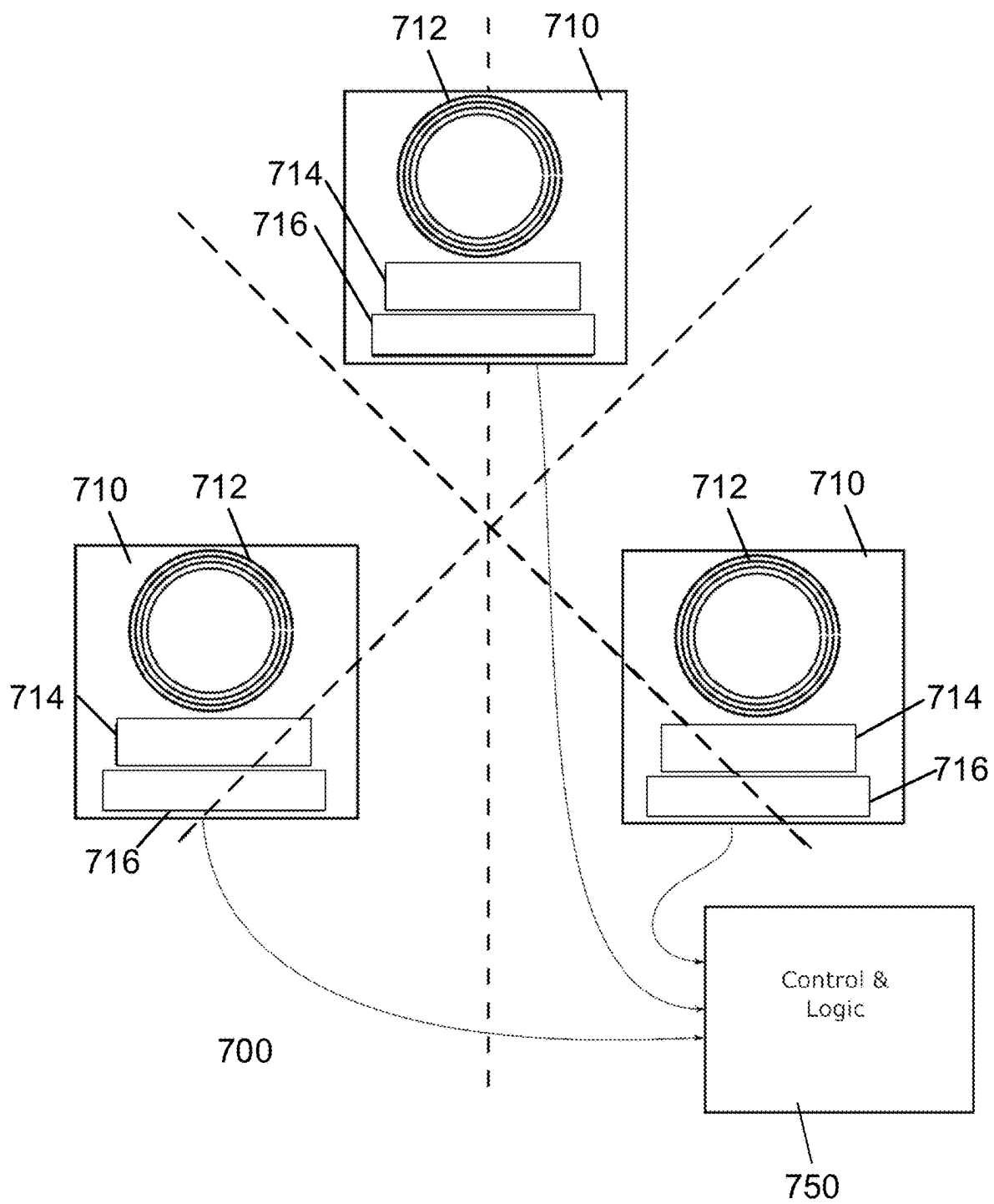
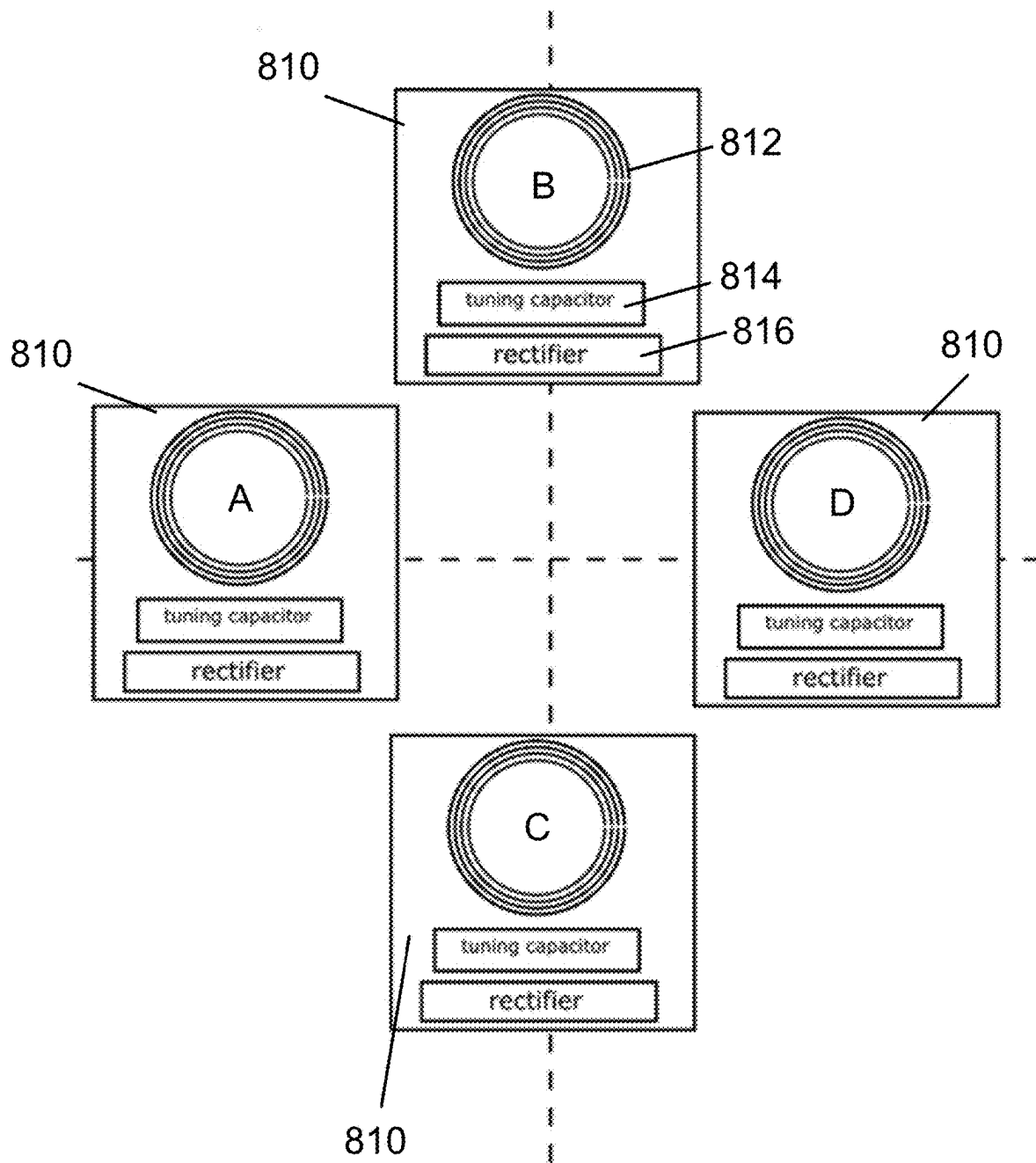


FIG. 7



800

Figure 8

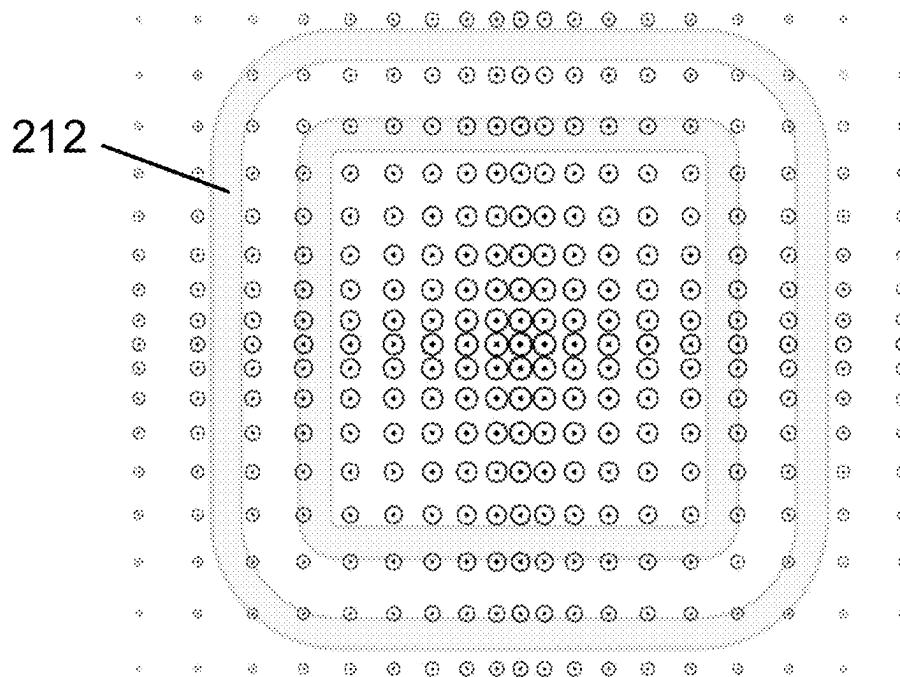


FIG. 9

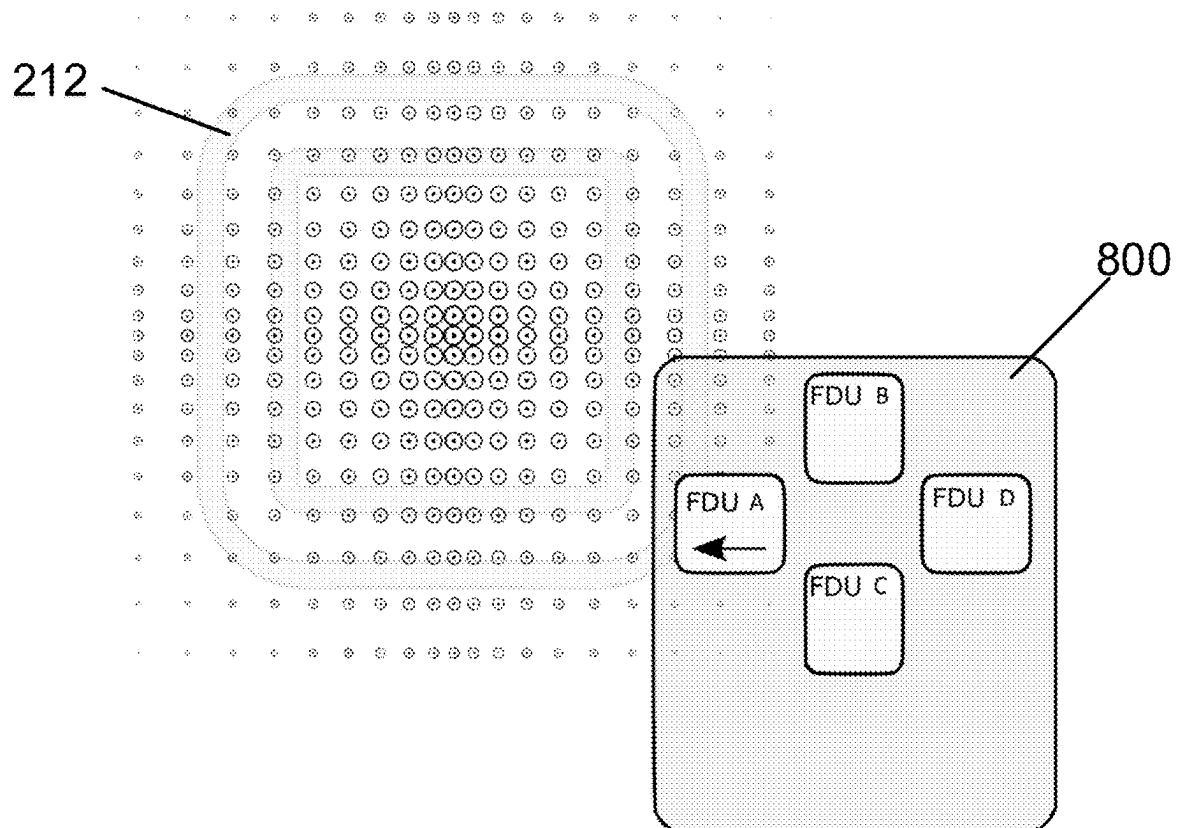


FIG. 10

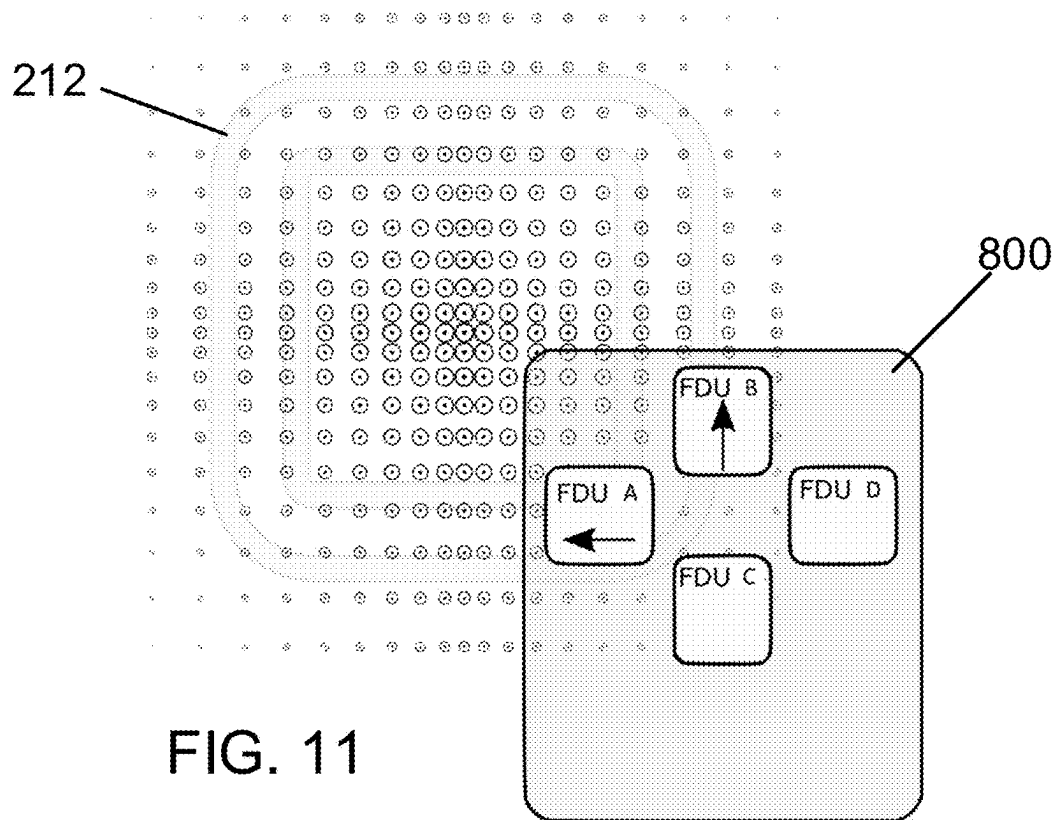


FIG. 11

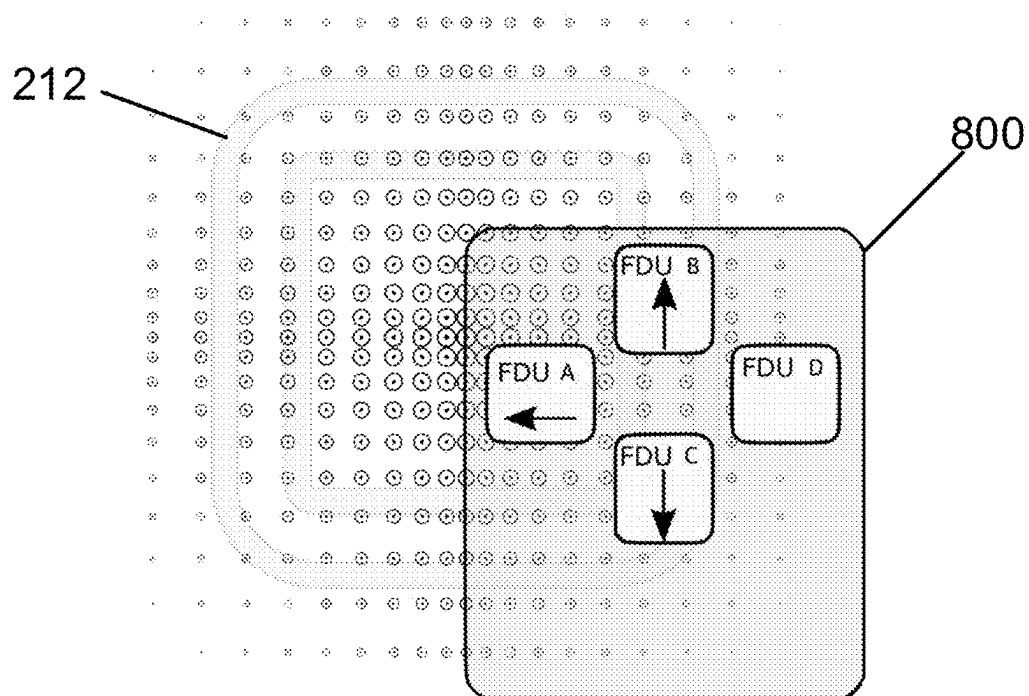


FIG. 12

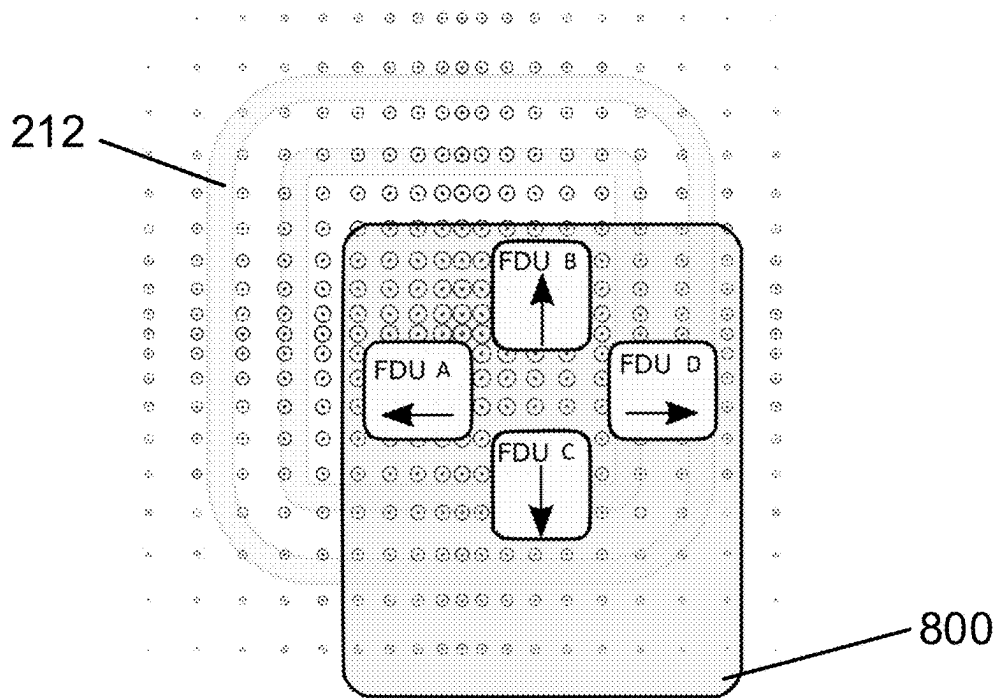


FIG. 13

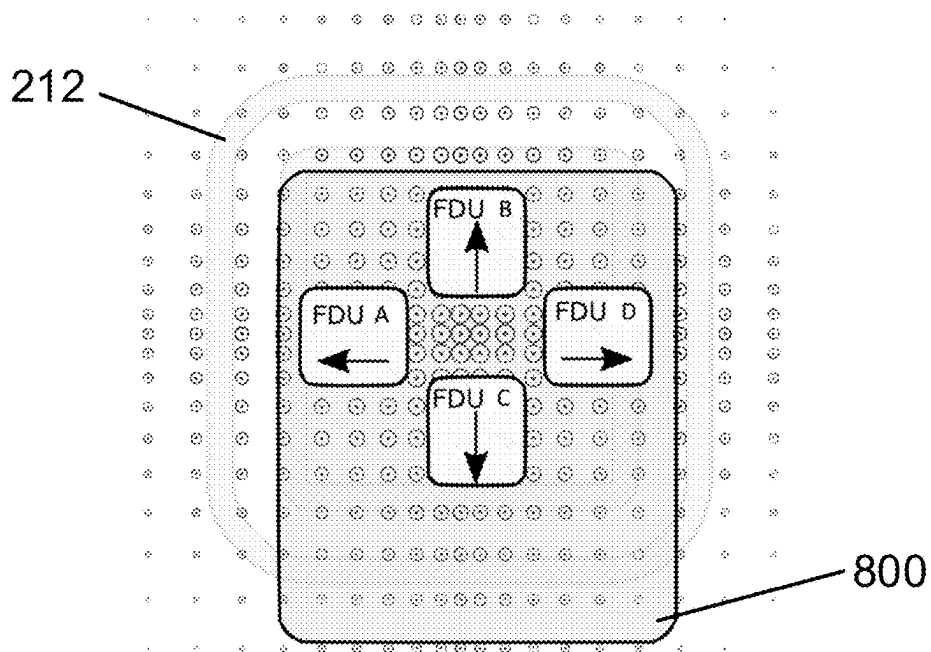


FIG. 14

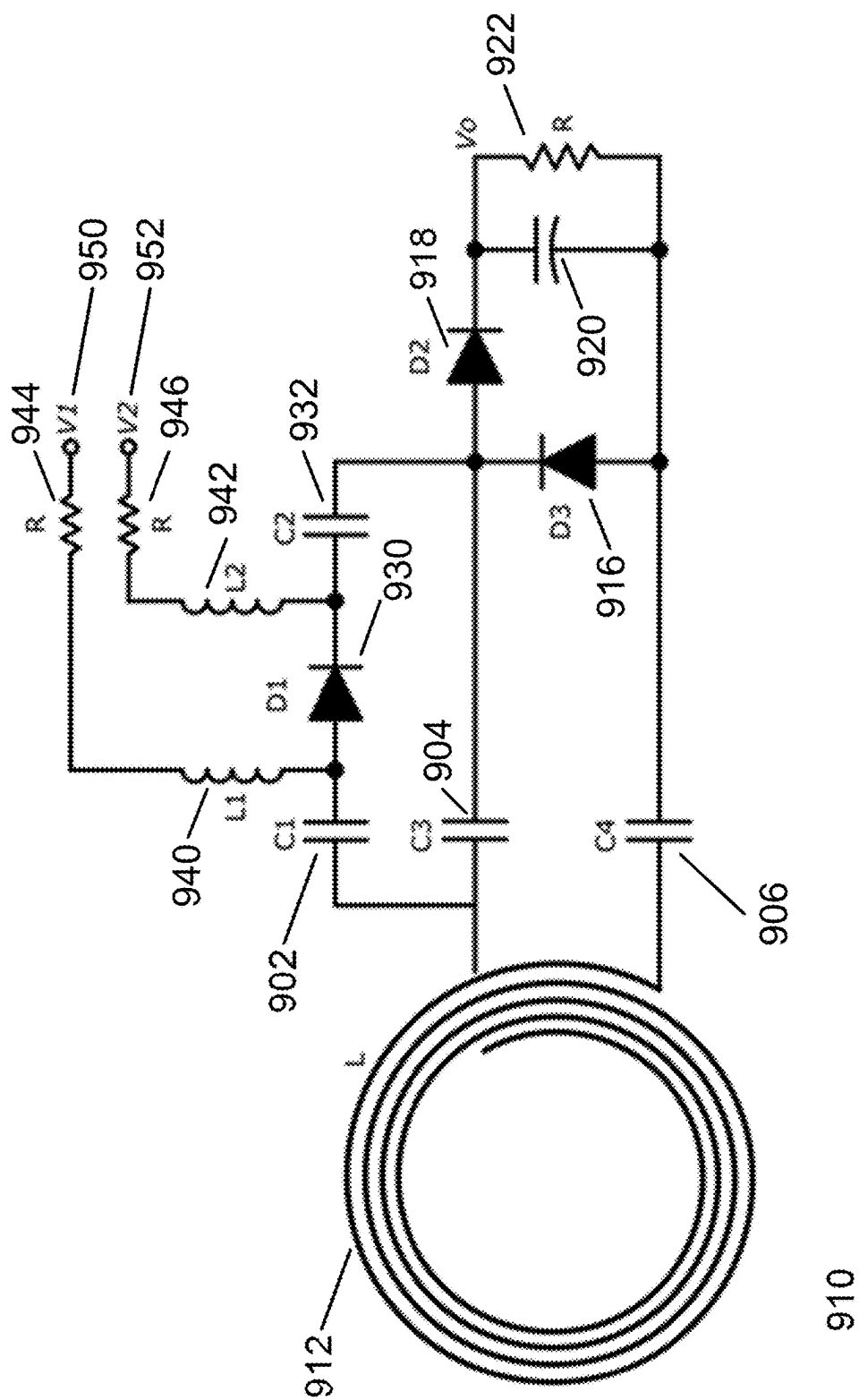


Figure 15

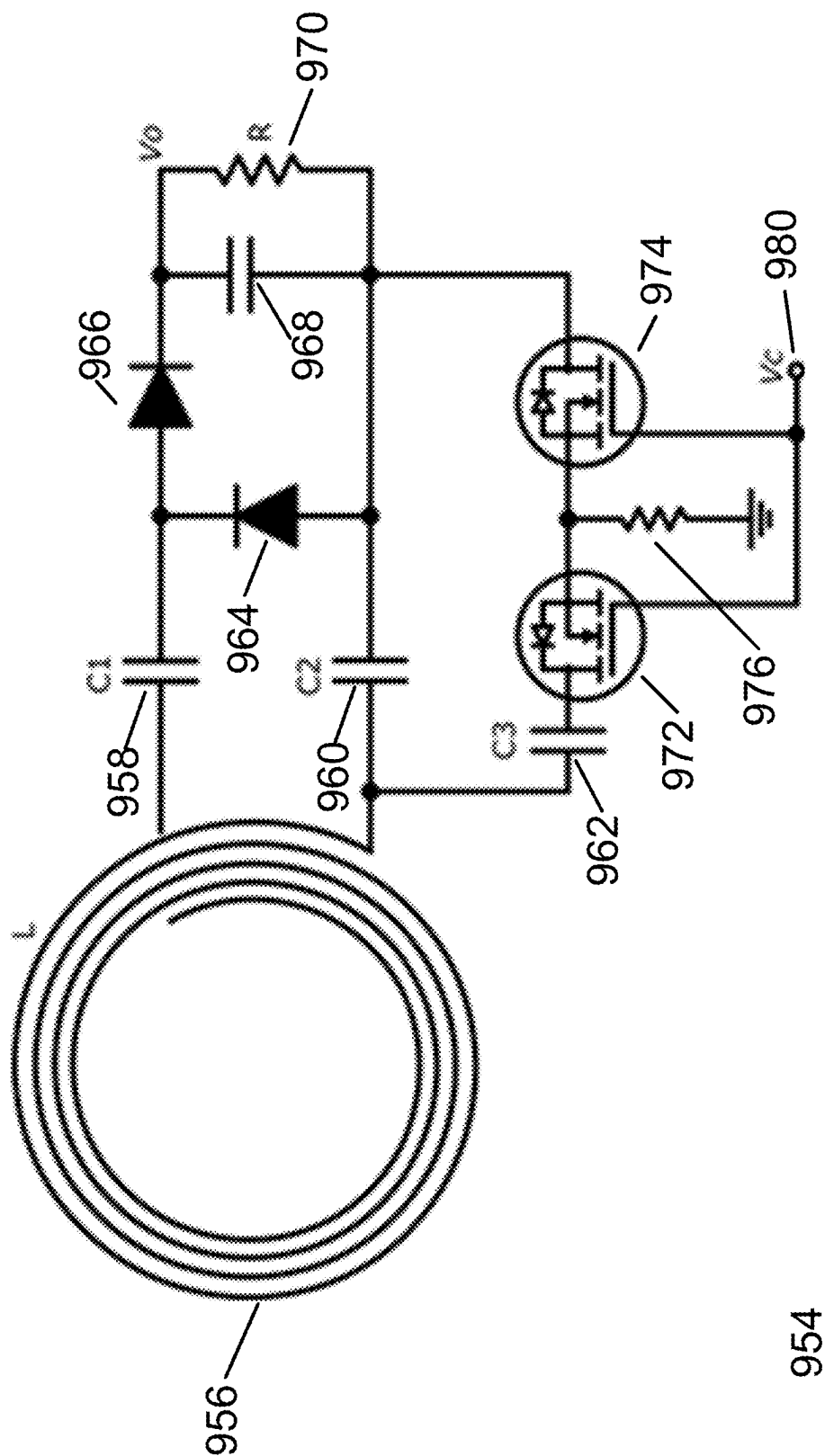
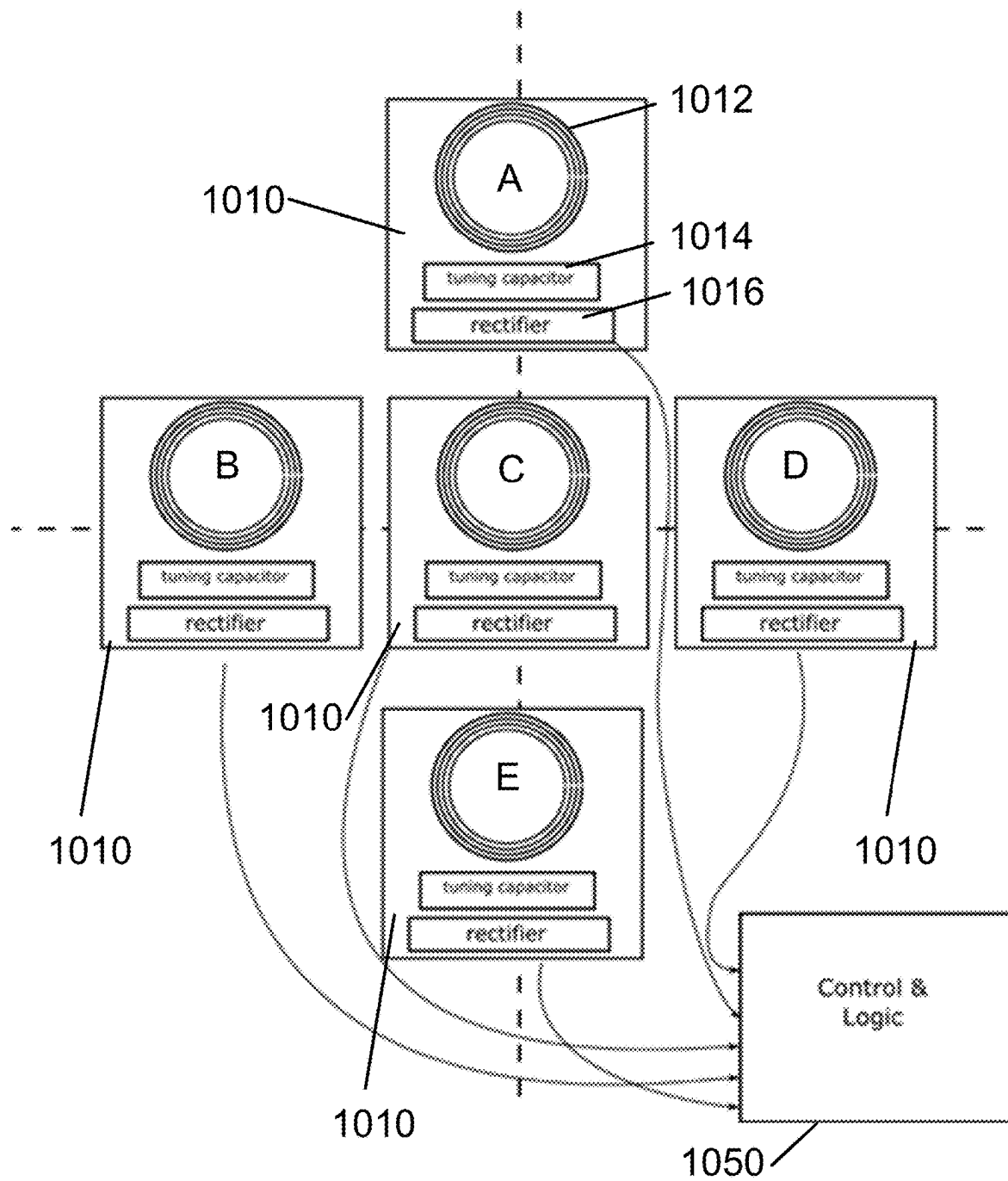


Figure 16



1000

Figure 17

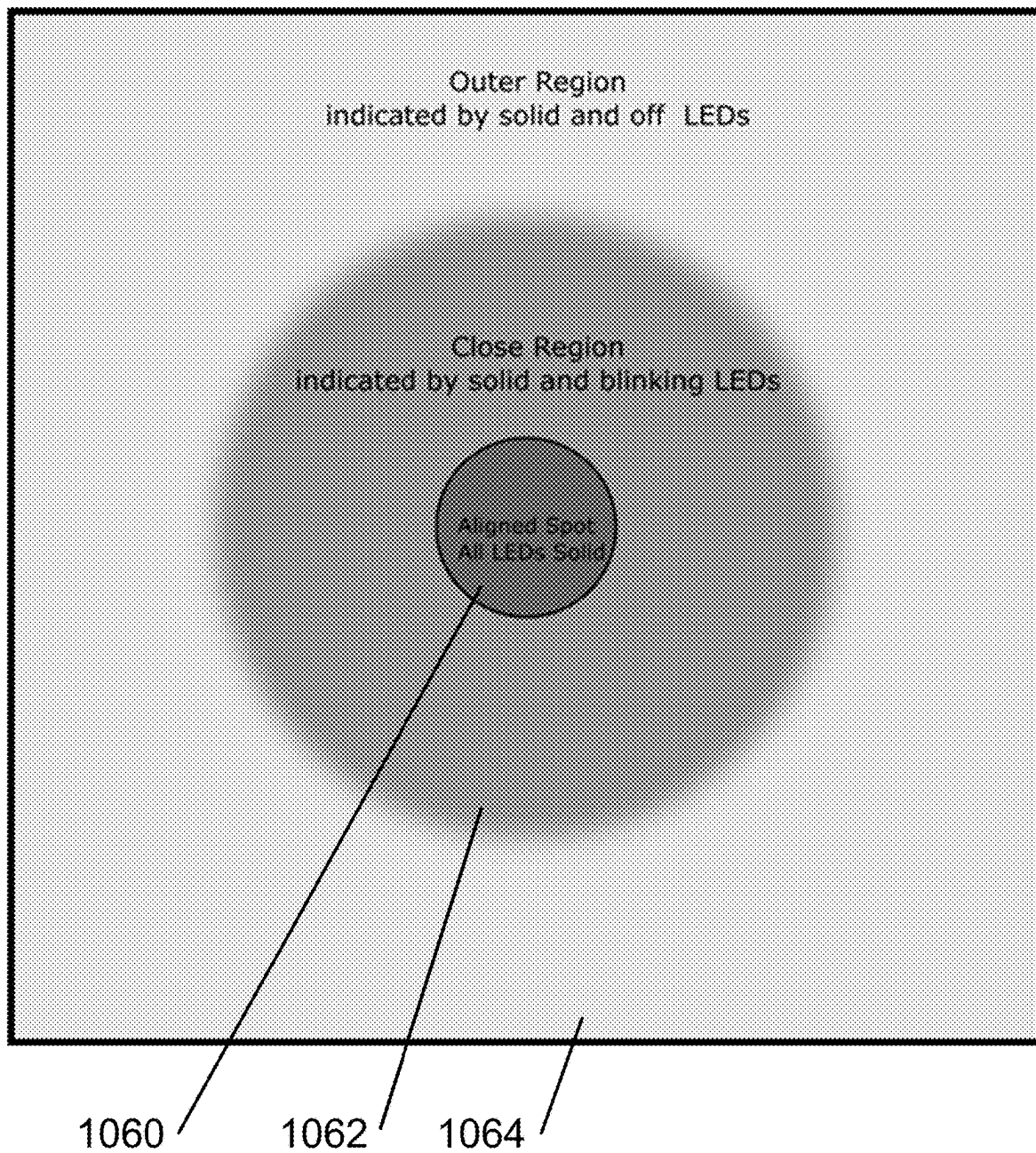


Figure 18

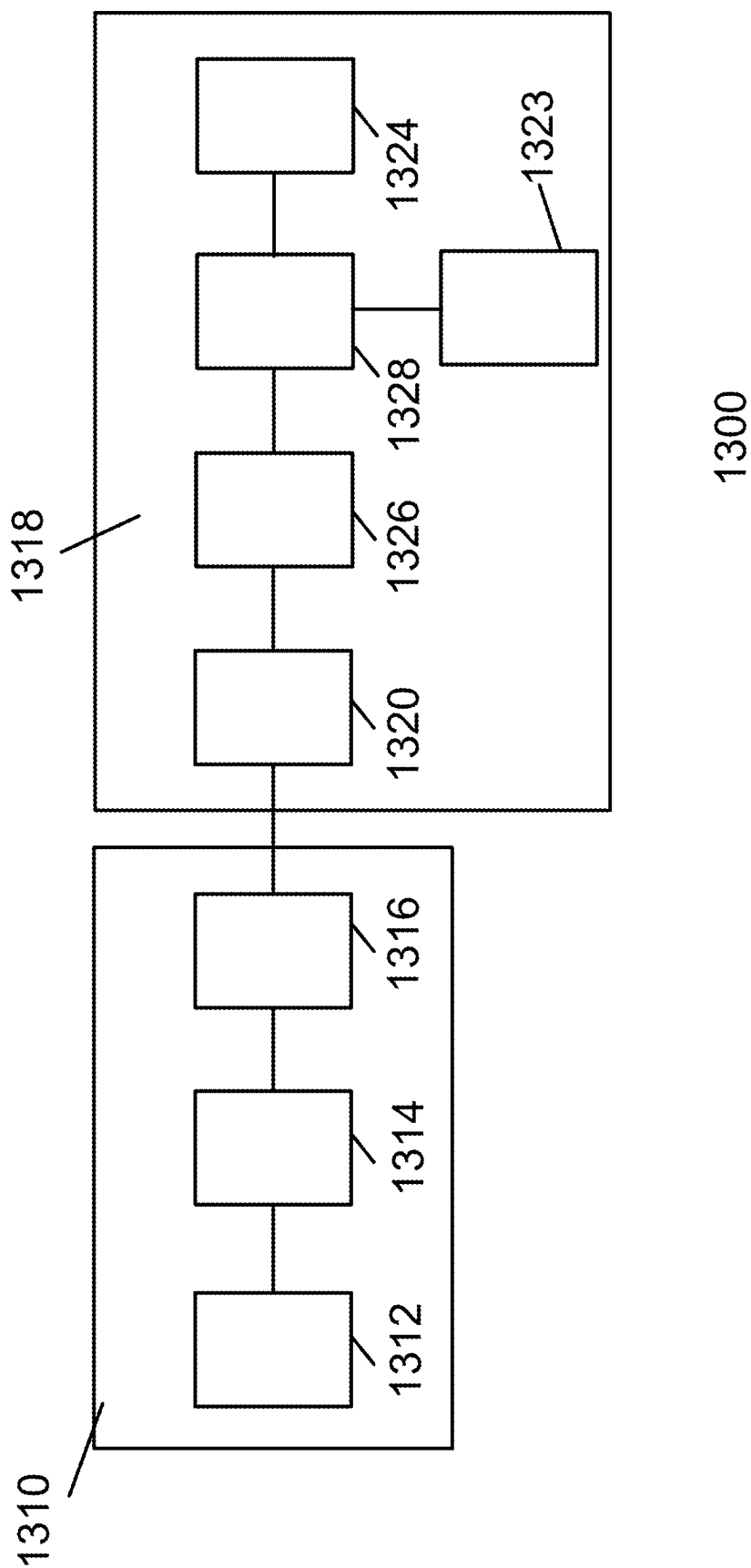


Figure 19

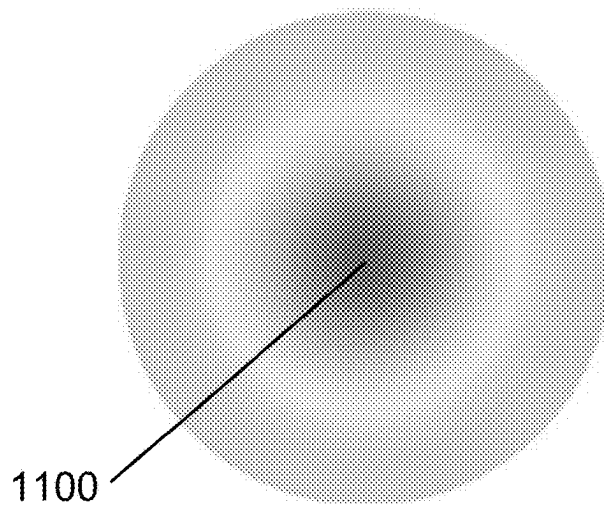


Figure 20A

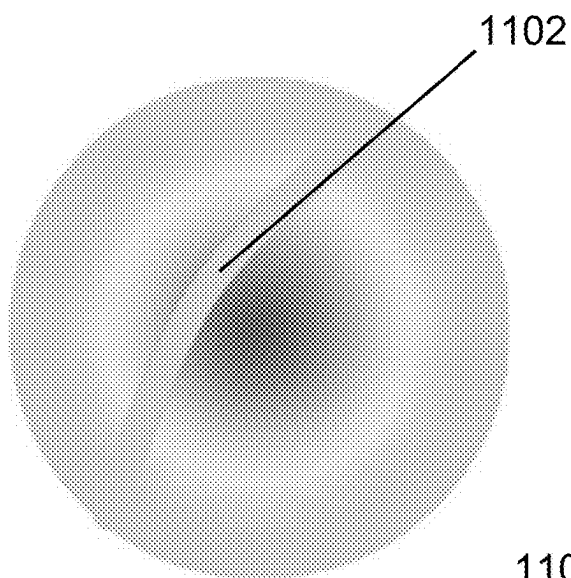


Figure 20B

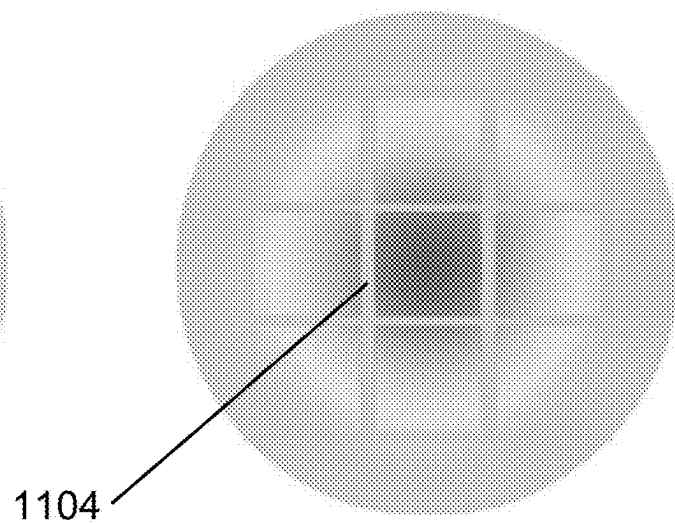


Figure 20C

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ALIGNMENT DEVICE FOR ALIGNING TRANSMITTER AND RECEIVER OF WIRELESS POWER TRANSFER SYSTEM, AND METHOD THEREFOR

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation of U.S. application Ser. No. 17/083,735, filed Oct. 29, 2020, which claims the benefit of U.S. Provisional Application No. 62/927,224 filed on Oct. 29, 2019, the disclosure of each of which is incorporated by reference herein in its entirety.

FIELD

The subject disclosure relates generally to wireless power transfer and in particular, to an alignment device for aligning a transmitter and receiver of a wireless power transfer system, and a method therefor.

BACKGROUND

Wireless charging and wireless power transfer systems are becoming an increasingly important technology to enable the next generation of devices. The potential benefits and advantages offered by the technology is evident by the increasing number of manufacturers and companies investing in the technology.

A variety of wireless power transfer systems are known. A typical wireless power transfer system includes a power source electrically connected to a wireless power transmitter, and a wireless power receiver electrically connected to a load.

In magnetic induction systems, the transmitter has a coil with a certain inductance that transfers electrical energy from the power source to a receiving coil with a certain inductance. Power transfer occurs due to coupling of magnetic fields between the inductors of the transmitter and receiver. The range of these magnetic induction systems is limited, and the inductors of the transmitter and receiver must be tightly coupled, i.e. have a coupling factor above 0.5 and be in optimal alignment for efficient power transfer.

There also exist resonant magnetic systems in which power is transferred due to coupling of magnetic fields between the inductors of the transmitter and receiver. The transmitter and receiver inductors are loosely coupled, i.e. have a coupling factor below 0.5. In resonant magnetic systems the inductors are resonated using at least one capacitor. In resonant magnetic systems, the transmitter is self-resonant and the receiver is self-resonant. The range of power transfer in resonant magnetic systems is increased over that of magnetic induction systems and alignment issues are rectified. While electromagnetic energy is produced in magnetic induction and resonant magnetic systems, the majority of power transfer occurs via the magnetic field. Little, if any, power is transferred via electric capacitive or resonant electric capacitive (electric fields).

The Qi wireless charging standard is an exemplary implementation of a magnetic induction system. The Qi wireless charging standard is used in low power consumer electronics such as smart phones and wearable devices. Furthermore, low cost power converters, coils and integrated circuits are available for use in the Qi wireless charging standard. The Qi wireless charging standard operates in the kHz frequency range. Accordingly, devices operating according to the Qi wireless charging standard have limited coupling range,

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require precise coil alignment and use ferrite-based coils, which can be heavy and fragile. Consequently, the application scope of the Qi wireless charging standard is limited.

In electrical capacitive systems, the transmitter and receiver have capacitive electrodes. Power transfer occurs due to coupling of electric fields between the capacitive electrodes of the transmitter and receiver. Similar, to resonant magnetic systems, there exist resonant electric systems in which the capacitive electrodes of the transmitter and receiver are made resonant using at least one inductor. In resonant electric systems, the transmitter is self-resonant and the receiver is self-resonant. Resonant electric systems have an increased range of power transfer compared to that of electric capacitive systems and alignment issues are rectified. While electromagnetic energy is produced in electric capacitive and resonant electric systems, the majority of power transfer occurs via the electric field. Little, if any, power is transferred via magnetic induction or resonant magnetic induction.

Although wireless power transfer techniques are known, improvements are desired.

SUMMARY

It should be appreciated that this Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description of Embodiments. This Summary is not intended to be used to limit the scope of the claimed subject matter.

Accordingly, in one aspect there is provided an alignment device comprising: a coil configured to generate an induced voltage from a magnetic field, or an electrode configured to generate an induced voltage from an electric field; and a comparator configured to compare the induced voltage to a threshold voltage and activate an indicator based on the comparison.

In one or more embodiments, the induced voltage is proportional to the strength of the magnetic field intersecting the coil, or to the electric field intersecting the electrode.

In one or more embodiments, the alignment device is configured to align a transmitter and a receiver for optimal power transfer efficiency.

In one or more embodiments, the alignment device is configured to align a transmitter coil and a receiver coil for optimal power transfer efficiency.

In one or more embodiments, the alignment device is configured for use with a high frequency wireless power transfer system.

In one or more embodiments, the coil or electrode forms part of a field detection unit (FDU).

In one or more embodiments, the FDU comprises at least one tuning capacitor configured to tune the coil.

In one or more embodiments, the FDU comprises a rectifier configured to rectify the induced voltage from alternating current (AC) to direct current (DC).

In one or more embodiments, the FDU comprises at least one diode configured to add capacitors to the coil to decrease a resonant frequency of the coil

In one or more embodiments, the alignment device comprises a plurality of FDUs, each FDU comprising an individual coil configured to generate an induced voltage from a magnetic field, or an individual electrode configured to generate an induced voltage from an electric field.

In one or more embodiments, the alignment device comprises four FDUs orthogonally positioned with respect to each other in a plane.

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In one or more embodiments, the FDUs are positioned equidistant to each other in the plane.

In one or more embodiments, the alignment device comprises five FDUs orthogonally positioned with respect to each other in a plane.

In one or more embodiments, four FDUs are positioned equidistant to a central FDU in the plane.

In one or more embodiments, each FDU is associated with an individual indicator.

In one or more embodiments, the comparator forms part of a main board.

In one or more embodiments, the main board further comprises the indicator.

In one or more embodiments, the main board further comprises a voltage divider configured to scale down voltage.

In one or more embodiments, the main board further comprises a sensitivity control configured to control the threshold voltage.

In one or more embodiments, the alignment device further comprises a spirit level.

According to another aspect there is provided an alignment device for determining an optimal alignment of a transmitter and a receiver configured to extract power from the transmitter via magnetic field coupling or electric field coupling.

In one or more embodiments, the alignment device comprises a coil configured to generate an induced voltage from a magnetic field.

In one or more embodiments, the alignment device comprises an electrode configured to generate an induced voltage from an electric field.

In one or more embodiments, the alignment device comprises an indicator configured to activate based on a comparison between the induced voltage and a threshold voltage.

In one or more embodiments, the alignment device further comprises a comparator configured to compare the induced voltage to the threshold voltage.

In one or more embodiments, the alignment device comprises any of the features or elements of the described alignment devices.

According to another aspect there is provided, a method comprising:

- a) activating a transmitter positioned on one side of a material;
- b) positioning an alignment device on another side of the material opposite the transmitter;
- c) generating, via a coil of the alignment device, an induced voltage from a magnetic field generated by the transmitter, or generating, via an electrode of the alignment device, an induced voltage from an electric field generated by the transmitter;
- d) activating an indicator of the alignment device based on a comparison of the induced voltage with a threshold voltage;
- e) repositioning the alignment device relative to the transmitter; and
- f) repeating steps c) to e) until optimal power transfer efficiency between the transmitter and the alignment device is obtained.

In one or more embodiments, the method further comprises positioning a receiver at a position at which optimal power transfer efficiency between the transmitter and the alignment device is obtained.

In one or more embodiments, the alignment device of the method comprises any of the described alignment devices.

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BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments will now be described more fully with reference to the accompanying drawings in which:

FIG. 1 is a block diagram of a wireless power transfer system;

FIG. 2 is a block diagram of a transmitter and receiver of a high frequency wireless power transfer system mounted to a material;

FIG. 3 is block diagram of an alignment device in accordance with an aspect of the subject disclosure;

FIG. 4 is a partial schematic layout of a field detection unit (FDU) of the alignment device of FIG. 3;

FIG. 5 is a plan view of a coil of the FDU of FIG. 4;

FIG. 6 is a partial schematic layout of the FDU of FIG. 4 with an alternating magnetic field present during operation;

FIG. 7 is a partial block diagram of another embodiment of the alignment device of FIG. 3;

FIG. 8 is partial block diagram of another embodiment of the alignment device of FIG. 3;

FIG. 9 is a magnetic field density plot generated by the transmitter of the high frequency wireless power transfer system of FIG. 2;

FIG. 10 is a plan view of the magnetic field density plot of FIG. 9 with the alignment device of FIG. 8;

FIG. 11 is another plan view of the magnetic field density plot of FIG. 9 with the alignment device of FIG. 8 during operation;

FIG. 12 is another plan view of the magnetic field density plot of FIG. 9 with the alignment device of FIG. 8 during operation;

FIG. 13 is another plan view of the magnetic field density plot of FIG. 9 with the alignment device of FIG. 8;

FIG. 14 is another plan view of the magnetic field density plot of FIG. 9 with the alignment device of FIG. 8 during operation;

FIG. 15 is a partial schematic layout of another FDU of the alignment device of FIG. 3;

FIG. 16 is a partial schematic layout of another FDU of the alignment device of FIG. 3;

FIG. 17 is a partial block diagram of another embodiment of the alignment device of FIG. 3;

FIG. 18 is a proximity diagram indicating regions of proximity of an alignment device to an optimal alignment;

FIG. 19 is a block diagram of another embodiment of the alignment device of FIG. 3; and

FIGS. 20A-20C are spatial distribution diagrams of detected magnetic fields.

DETAILED DESCRIPTION OF EMBODIMENTS

The foregoing summary, as well as the following detailed description of certain examples will be better understood when read in conjunction with the appended drawings. As used herein, an element or feature introduced in the singular and preceded by the word "a" or "an" should be understood as not necessarily excluding the plural of the elements or features. Further, references to "one example" or "one embodiment" are not intended to be interpreted as excluding the existence of additional examples or embodiments that also incorporate the described elements or features. Moreover, unless explicitly stated to the contrary, examples or embodiments "comprising" or "having" or "including" an element or feature or a plurality of elements or features having a particular property may include additional elements or features not having that property. Also, it will be appreciated that the terms "comprises", "has", "includes" means

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"including by not limited to" and the terms "comprising", "having" and "including" have equivalent meanings. It will also be appreciated that like reference characters will be used to refer to like elements throughout the description and drawings.

As used herein, the terms "adapted" and "configured" mean that the element, component, or other subject matter is designed and/or intended to perform a given function. Thus, the use of the terms "adapted" and "configured" should not be construed to mean that a given element, component, or other subject matter is simply "capable of" performing a given function but that the element, component, and/or other subject matter is specifically selected, created, implemented, utilized, and/or designed for the purpose of performing the function. It is also within the scope of the subject disclosure that elements, components, and/or other subject matter that are described as being adapted to perform a particular function may additionally or alternatively be described as being configured to perform that function, and vice versa. Similarly, subject matter that is described as being configured to perform a particular function may additionally or alternatively be described as being operative to perform that function.

It will be understood that when an element is referred to as being "on," "attached" to, "connected" to, "coupled" with, "contacting," etc., another element, it can be directly on, attached to, connected to, coupled with or contacting the other element or intervening elements may also be present.

It should be understood that use of the word "exemplary", unless otherwise stated, means 'by way of example' or 'one example', rather than meaning a preferred or optimal design or implementation.

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as is commonly understood by one of skill in the art to which the subject disclosure pertains.

As used herein, the terms "approximately", "about", "approximately", "generally" etc. represent an amount or condition close to the stated amount or condition that still performs the desired function or achieves the desired result. For example, the terms "approximately", "about", "approximately", "generally" etc. may refer to an amount or condition that is within engineering tolerances that would be readily appreciated by a person skilled in the art.

Turning now to FIG. 1, a wireless power transfer system generally identified by reference numeral 100 is shown. The wireless power transfer system 100 comprises a transmitter 110 comprising a power source 112 electrically connected to a transmit element 114, and a receiver 120 comprising a receive element 124 electrically connected to a load 122. Power is transferred from the power source 112 to the transmit element 114. The power is then transferred from the transmit element 114 to the receive element 124 via resonant or non-resonant electric or magnetic field coupling. The power is then transferred from the receive element 124 to the load 122. Exemplary wireless power transfer systems 100 include a high frequency inductive wireless power transfer system as described in U.S. patent application Ser. No. 17/018,328, the relevant portions of which are incorporated herein.

Turning now to FIG. 2, another exemplary wireless power transfer system is shown. In this embodiment, the wireless power transfer system is a high frequency wireless power transfer system 200 as described in the above-incorporated '328 application. In this embodiment, the high frequency wireless power transfer system 200 is an inductive system. One of reasonable skill in the art will appreciate that the high

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frequency wireless power transfer system 200 may be configured to transfer power via high frequency magnetic inductive coupling or high frequency electric capacitive coupling. In magnetic inductive coupling systems, the majority of power transfer occurs via the magnetic field. Little, if any, power is transferred via electric capacitive or resonant electric capacitive (electric fields). In electric capacitive coupling systems, the majority of power transfer occurs via the electric field. Little, if any, power is transferred via magnetic inductive or resonant magnetic induction.

In this embodiment, the high frequency wireless power transfer system 200 is configured to transfer power via high frequency magnetic field coupling. The high frequency wireless power transfer system 200 comprises a transmitter 210 configured to operate at a given frequency, and a receiver 220 configured to operate at the operational frequency of the transmitter 210. As shown in FIG. 2, the transmitter 210 is positioned on a material 230. The material 230 is fabricated from any type of suitable material or material combination that is not conductive or magnetic, e.g. wood, glass, stone, brick, concrete, plastic, except for materials or a combination of materials that would cause termination of the fields prematurely, i.e. act as a shield. In this embodiment, the material 230 forms part of a wall. The receiver 220 is positioned on the opposite side of the material 230, such that the material 230 is directly between the transmitter 210 and receiver 220. One of reasonable skill in the art will recognize that more than one transmitter 210 and receiver 220 is possible.

In this embodiment, the transmitter 210 comprises a transmitter coil 212, and the receiver 220 comprises a receiver coil 222. One of skill in the art will recognize that more than one transmitter coil 212 and receiver coil 222 is possible.

The transmitter 210 operates in current-mode output (constant current output). In current-mode output, the transmitter 210 is configured to generate a magnetic field without the requirement for a receiver 220 to be present near the transmitter 210.

Generally, current-mode output high frequency wireless power transfer systems differ from voltage-mode output (constant voltage output) high frequency wireless power transfer systems in that voltage-mode output transmitters 210 cannot generate and maintain a magnetic field without a receiver 220 present near the transmitter 210. If a receiver 220 is not present in a voltage-mode output high frequency wireless power transfer system, the transmitter 210 will essentially operate in a short-circuit condition, and therefore cannot sustain generation of a magnetic field.

Power transfer from transmitter 210 to receiver 220 occurs through the material 230. In order to maximize the coupling coefficient value and the highest power transfer efficiency, the transmitter 210 and receiver 220 should be optimally aligned. If the material 230 is opaque or if it completely obstructs view of the position of either the transmitter 210 or receiver 220, or both, it may be problematic to optimally align the transmitter 210 and receiver 220.

In optimal alignment of the receiver 220 with the transmitter 210, the receiver coil 222 is in optimal alignment with the transmitter coil 212.

Turning now to FIG. 3, a block diagram of an alignment device 300 in accordance with an aspect of the subject disclosure is shown. Given a certain fixed distance away from the transmitter 210, the alignment device 300 determines the position at which, when a receiver 220 is installed, the transmitter 210 and receiver 220 will be in optimal

alignment to achieve the maximum coupling coefficient value and hence, the highest power transfer efficiency. The transmitter coil 212 and receiver coil 222 are in optimal alignment when their centre axes normal to the transmitter coil 212 and the receiver coil 222 are collinear. The centre axis of each of the transmitter coil 212 and the receiver coil 222 is the axis extending through the centre of mass of the respective coil 212 and 222.

In particular, the alignment device 300 is configured to generate an induced voltage from a magnetic field generated by the transmitter 210. Specifically, the alignment device 300 is configured to generate an induced alternating voltage when intersected by the alternating magnetic field generated by the transmitter 210. Based on the induced alternating voltage, the alignment device 300 is configured to determine the position of the alignment device 300 in relation to the transmitter 210 or transmitter coil 212. The receiver 220 and receiver coil 222 may then be positioned in the position in which power transfer efficiency is maximized between the transmitter and receiver coils 212 and 222 as determined by the alignment device 300.

The alignment device 300 comprises a field detection unit (FDU) 310 and a main board 318. The FDU 310 comprises at least one coil 312, at least one tuning capacitor 314 and a rectifier 316. The coil 312 is electrically connected to the tuning capacitor 314. The tuning capacitor 314 is electrically connected to the coil 312 and the rectifier 316. The FDU 310 is electrically connected to the main board 318. Specifically, the rectifier 316 of the FDU 310 is electrically connected to a voltage divider 320 of the main board 318. The main board 318 comprises the voltage divider 320, a comparator, which in this embodiment takes the form of a comparator circuit 322, a sensitivity control 323 and an indicator 324. The voltage divider 320 is electrically connected to the rectifier 316 of the FDU 310. The voltage divider 320 is also electrically connected to the comparator circuit 322. The comparator circuit 322 is electrically connected to the indicator 324 via a driving circuit (not shown). The indicator 324 is electrically connected to the comparator circuit 322 via a driving circuit (not shown).

The comparator circuit 322 is configured to compare a voltage signal of the rectifier 316 against a preset threshold voltage. In this embodiment, the indicator 324 associated with the FDU 310 is a light emitting diode (LED). The LED is driven by an LED driving circuit (not shown). The LED driving circuit, which, in this embodiment, comprises a transistor (not shown), is triggered by output from the comparator circuit 322. The sensitivity control 323 is electrically connected to the comparator circuit 322. The sensitivity control 323 is configured to adjust and set a threshold voltage. In this embodiment, the sensitivity control 323 is a turnable knob, dial or the like.

The indicator 324 assists in determining the optimal alignment position at which the maximum coupling coefficient and the highest wireless power transfer efficiency is achieved. For example, the indicator 324 comprises a visual indicator, including, but not limited to, an LED or other type of light/diode; an audible indicator; any type of sensory indicator, including but not limited to, vibration; and any combination of available types of indicators 324, not limited to the types of indicators described herein.

One of reasonable skill in the art will recognize that multiple FDUs 310 may be attached to a single main board 318. Furthermore, one of reasonable skill in the art will appreciate that multiple indicators 324 on a single main board 318 are also possible. For example, one indicator 324 for each FDU 310 may be provided.

In this embodiment, the alignment device 300 is configured for use with the high frequency inductive wireless power transfer system as described in the above-incorporated '328 application. In this embodiment, the alignment device 300 is configured to operate with the current-mode output transmitter 210, both independent from, and in the absence of the receiver 220.

In a voltage-mode output high frequency wireless power transfer system, the alignment device 300 cannot be used without the receiver 220 present. Accordingly, in voltage-mode output high frequency wireless power transfer systems, the alignment device 300 is integrated into the receiver 220. Conversely, the current-mode output high frequency wireless power transfer system 200 will allow the alignment device 300 to operate while being physically separate from the receiver 220, (i.e. decoupled, from the receiver 220), and therefore, allowing the alignment device 300 to operate independently with the transmitter 210, in the complete absence of the receiver 220. As one of reasonable skill in the art will appreciate, the alignment device 300 may alternatively be integrated into the receiver 220 of a current-mode output high frequency wireless power transfer system.

Turning now to FIG. 4, the FDU 310 of the alignment device 300 is further illustrated. As previously stated, the FDU 310 comprises at least one coil 312. The coil 312 is electrically connected in series to tuning capacitors 314. The tuning capacitors 314 are electrically connected to the coil 312 and to the rectifier 316. The combination of the electrically connected coil 312, tuning capacitors 314 and rectifier 316 forms the FDU 310. The FDU 310 is electrically connected to the main board 318. In this embodiment, the alignment device 300 comprises a single FDU 310. In another embodiment, the alignment device 300 comprises multiple FDUs 310, for example, four FDUs 310. Each FDU 310 is identical.

Turning now to FIG. 5, the coil 312 is further illustrated. In this embodiment, the coil 312 is implemented on a printed circuit board (PCB) made of FR4 PCB material. In this embodiment, the coil 312 is a planar coil consisting of multiple turns and is in the approximate shape of a square. In this embodiment, the total number of turns of the coil 312 is four, each turn is 1 mm thick, and the spacing between each turn is 0.3 mm. One of reasonable skill in the art will recognize that the coil 312 could be any other shape, such as, but not limited to, spiral, circular, hexagonal or octagonal. One of reasonable skill in the art will also recognize that the number of turns, the turn thickness and the spacing between the turns could be any suitable value. In this embodiment, the coil 312 has an outer width and height, D1, which is 39 mm, and inner width and height, D2, which is 29.5 mm. One of reasonable skill in the art will recognize that the dimensions D1 and D2 of the coil 312 could be any suitable value. In this embodiment, the inductance (L) of the coil 312 is 1.2 uH. One of reasonable skill in the art will recognize that the inductance of the coil 312 is exemplary. The inductance may be as high as 6 to 8 uH. Generally, the inductance of the coil 312 is bound by the resonant frequency of the transmitter coil 212. Increasing the inductance of the coil 312 will decrease the self-resonant frequency of the coil 312 such that the self-resonant frequency of the coil 312 approaches the resonant frequency, which may be problematic. A higher inductance may however, provide higher sensitivity and field detection during operation of the alignment device 300.

The optimal placement of the alignment device 300 coincides with the optimal alignment of the receiver 220 in relation to the transmitter 210. Optimal alignment of the transmitter 210 and the receiver 220 coincides with optimal

alignment of the transmitter coil **212** and the receiver coil **222**. Optimal alignment of the transmitter coil **212** and the receiver coil **222** is the position at which the maximum coupling coefficient value and the highest wireless power transfer efficiency is achieved.

During operation, the transmitter **210** of the wireless power transfer system **200** is activated and powered on. The transmitter coil **212** generates a constant alternating current (AC) magnetic field. The receiver **220** can be aligned with the transmitter **210** to allow for power to be transferred wirelessly from the transmitter coil **212** to the receiver coil **222**. For alignment to be optimal between the transmitter **210** and the receiver **220**, the transmitter coil and **212** the receiver coil **222** must be in optimal alignment. Coupling and power transfer can still occur without optimal alignment of the transmitter coil **202** and receiver coil **212**; however, the performance of the wireless power transfer system **200** will be degraded.

As previously stated, given a certain fixed distance away from the transmitter **210**, the alignment device **300** determines the position at which, when the receiver **220** is installed, the transmitter **210** and receiver **220** will be in optimal alignment to achieve the maximum coupling coefficient value and hence, the highest power transfer efficiency. The transmitter coil **212** and receiver coil **222** are in optimal alignment when their centre axes normal to the transmitter coil **212** and the receiver coil **222** are collinear. In other words, the transmitter coil **212** and receiver coil **222** are in optimal alignment when the axis extending through the centre of mass of the respective coil **212** and **222** are collinear.

During operation of the alignment device **300**, the coil **312** is intersected by an AC magnetic field generated by the transmitter coil **212**. The coil **312** generates an induced alternating voltage from the AC magnetic field. The induced voltage is used to determine the position of the alignment device **300** in relation to the transmitter **210** of the high frequency wireless power transfer system **200** that operates at constant-current mode in the transmitter coil **212**.

Specifically, the tuning capacitors **314** of the FDU **310** tune the coil **312** to the resonant frequency of the transmitter coil **212** to generate an induced voltage from the AC magnetic field. The coil **312** induces an alternating voltage from the AC magnetic field and outputs an AC voltage signal. The induced alternating voltage is proportional to the strength of the AC magnetic field. The AC voltage signal is passed from the coil **312** to the rectifier **316**. The rectifier **316** rectifies the voltage signal from AC to DC. The DC voltage signal is then passed to the main board **318**. The voltage divider **320** scales down the DC voltage signal such that the DC voltage signal is compatible with the logic levels of the main board **318**. In this embodiment, the scale down factor of the voltage divider **320** is 10. However, one of reasonable skill in the art will recognize that the scale-down factor could be any other suitable value depending on the design of the main board **318**. Specifically, the voltage divider **320** scales down the DC voltage so that the DC voltage signal may be compared by the comparator circuit **322**. The scaled down DC voltage is measured by the comparator circuit **322**. The comparator circuit **322** compares the scaled down DC voltage to the preset threshold voltage as provided by the sensitivity control **323**. When the voltage is highest, (i.e. exceeds the threshold set by the sensitivity control **323** in the comparator circuit **322**), optimal alignment (or near-optimal alignment) is achieved. The comparator circuit **322** passes the results of the comparison to the indicator **324**. The scaled down DC voltage/preset

threshold voltage comparison determines to switch on the indicator **324** or not. Specifically, the comparison determines whether the LED of the indicator **324** is switched on or not. The indicator **324** indicates whether optimal alignment has been achieved.

The alignment device **300** allows for the transmitter **210** and receiver **220** to be located on opposite sides of material **230**, such as a wall or window. The alignment device **300** allows the optimal position of the transmitter coil **212** and receiver coil **222** to be determined, and therefore achieves the maximum coupling coefficient value and the highest wireless power transfer efficiency through the material **230**.

As shown in FIG. 6, during operation of the alignment device **300**, the coil **312** is subjected to an AC magnetic field in the direction indicated by arrows A. When subjected to the AC magnetic field, the coil **312** is intersected by the alternating magnetic field. The AC magnetic field that intersects the coil **312** induces an alternating voltage in the coil **312**. FIG. 6 shows an example of the direction of the magnetic field lines in relation to the coil **312**.

Although a particular configuration of the alignment device **300** has been described, one of reasonable skill in the art will appreciate that other configurations are possible. Turning now to FIG. 7, another embodiment of an alignment device generally identified by reference numeral **700** is shown. The alignment device **700** comprises all of the elements of the previously described alignment device **300** unless otherwise stated. The alignment device **700** functions similarly to the previously described alignment device **300** unless otherwise stated. The alignment device **700** comprises three FDUs **710**, each comprising a coil **712**, at least one tuning capacitor **714** and a rectifier **716**. The three FDUs **710** are coplanar and are arranged in an equilateral formation. Each FDU **710** is electrically connected to the main board (not shown). The main board of the alignment device **300** is identical to the previously described main board **318**. In the illustrated embodiment, the main board is incorporated into a control and logic module **750**.

Using three coils **712**, the module **750** is configured to triangulate the optimal position of the coils **712** in relation to the transmitter coil **212**. When all coils **712** are intersected by the alternating magnetic field equally, (or near equally), optimal alignment has been achieved, as will be described. One of reasonable skill in the art will recognize that the alignment device may also comprise further control and logic components, including, but not limited to, the use of a microprocessor, microcontroller, logic processor, or other possible controls.

FIG. 8 shows another embodiment of an alignment device generally identified by reference numeral **800**. The alignment device **800** comprises all of the elements of the previously described alignment device **300** unless otherwise stated. The alignment device **800** functions similarly to the previously described alignment device **300** unless otherwise stated. The alignment device **800** comprises four coplanar FDUs **810**. Each FDU **810** comprises a coil **812**, at least one tuning capacitor **814** and a rectifier **816**. Thus, the alignment device **800** comprises four coils **812**, four tuning capacitors **814**, and four rectifiers **816**. Each of the four coils **812** is electrically connected to a different tuning capacitor **814**. Each of the four tuning capacitors **814** is electrically connected to a different rectifier **816**. Each FDU **810** is electrically connect to the main board (not shown). The main board of the alignment device **800** is identical to the previously described main board **318**. As such, each rectifier **816** of each FDU **810** is electrically connected to the voltage divider **320** of the main board **318**.

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In this embodiment, the FDUs 810 are orthogonally positioned in respect to each other. The FDUs 810 are coplanar and positioned in the X-Y plane with two FDUs 810 opposite to, and laterally spaced from, each other along the X-axis and two FDUs 810 opposite to, and laterally spaced from, each other orthogonally along the Y-axis.

In this embodiment, the alignment device 800 comprises four FDU 810 each having a coil 812. The coils 812 are positioned at fixed distances from each other to detect the strength of AC magnetic field generated by the transmitter 210. The value of the detected magnetic field strength at each coil 812 is used to determine the optimal alignment position. In this embodiment, the indicator on the main board of the alignment device 800 is an LED. Similar to the alignment device 300, the alignment device 800 comprises a main board 318 comprising a voltage divider 320, a comparator 322, which in this embodiment takes the form of a comparator circuit, a sensitivity control 323 and indicators 324, one for each FDU. The main board and the components comprised thereon are identical to the previously described main board 318 and components comprised thereon. In this embodiment, the sensitivity control is a turnable knob, dial or the like.

Turning now to FIG. 9, an example of a magnetic field density plot generated from a single transmitter 210 of the high frequency wireless power transfer system 200 is shown. As shown in FIG. 9, the magnetic field is stronger along the center axis of the transmitter coil 212, and weaker near the edges of the plot. Efficient coupling of the transmitter coil 212 and the receiver coil 222 occurs when the transmitter coil 212 and receiver coil 222 are aligned along their center axes as the coupling coefficient will be maximized. As previously stated, the alignment device 800 detects the strongest magnetic field from the transmitter 210 along its center axis to determine the optimal alignment position for the receiver 220 to be mounted.

During operation, the alignment device 800 is positioned in proximity to the transmitter coil 212. The alignment device 800 is positioned such that the magnetic field intersects at least one of the coils 812 of one of the FDUs 810 of the alignment device 800, which induces an AC voltage in at least one of the coils 812 of the alignment device 800. The alternating magnetic field intersecting the coil in the FDU 810 will induce an alternating voltage in the coil 812. The induced alternating voltage is rectified to a DC voltage via the rectifier 816. Positioning of the alignment device 800 can be a manual process or an automated process.

Turning now to FIG. 10, the alignment device 800 with four FDUs 810 is shown over a magnetic field density plot generated from a single transmitter 210 of the high frequency wireless power transfer system 200. Depending on the position of the alignment device 800 in relation to the transmitter coil 212 of the transmitter 210, the coil 812 that is closest to the center of the transmitter coil 212 will have the highest rectified voltage as the magnetic field will be stronger. The remaining coils 812 will have a lower rectified voltage. The coil 812 with highest rectified (and scaled down) voltage, which exceeds the preset threshold voltage, will cause the indicator 824 to be triggered. The threshold voltage is set by a voltage sensitivity control 823 connected to the comparator circuit 822 on the main board 318. Consequently, the alignment device 800 is now relocated in the direction of the coil 812 which has the highest voltage.

FIG. 11 shows that as the alignment device 800 is moved in the direction of the highest rectified voltage, the next coil 812 that is now closer to the center of the magnetic field will now have an increase in its rectified voltage. As also shown

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in FIG. 11, the next coil to have an increase in rectified voltage must be orthogonal to the first coil 812.

For example, as shown in FIG. 10, if the first coil 812 with the highest rectified voltage is the left coil 812 of FDU 810 (A), the next coil 812 to have an increased rectified voltage will be either the top coil 812 of FDU 810 (B) or the bottom coil 812 of FDU 810 (C). Based on the orthogonality, the next coil 812 to have an increased rectified voltage cannot be the coil 812 of the FDU 810 (D). It is possible that the coils 812 of both FDU 810 (B) and FDU 810 (C) can simultaneously have an equal, or near equal, increase in rectified voltage, when coil 812 of FDU 810 (B) and coil 812 of FDU 810 (C) are both equidistant from the x axis, signifying that the alignment device 800 is aligned along the x axis.

As the first coil 812 of FDU 810 (A), intersects with the magnetic field of the transmitter 210, the rectified voltage is scaled down via the voltage divider 320 and is then measured by the main board 318 which sends the voltage data to the comparator circuit 322. The comparator circuit 322 compares the rectified voltage of FDU 810 (A) against the preset threshold voltage. When the rectified voltage of the FDU 810 (A) exceeds the preset voltage threshold, a signal is sent from the main board 318 to the indicator 324 associated with FDU 810 (A) to activate. The comparison of rectified voltage by the comparator circuit 322 against the preset threshold voltage repeats throughout the alignment process. The indicator 324 will turn on and off if the rectified voltage is higher or lower than the preset threshold. The indicator 824 activation is indicative of the direction in which the alignment device 800 should be repositioned in order to achieve alignment of the other FDUs 810. When all indicators 824 are activated, the alignment device 800 is in optimal alignment and all coils 812 are being intersected by the alternating magnetic field along the center axes of the transmitter coil 212. Following the intersection of the magnetic field with coil 812 of FDU 810 (A) and activation of the indicator 824, the alignment device 800 can be relocated in a new direction based on the position of the second coil 812 of a different FDU 810. In this embodiment the second coil 812 will either be the coil 812 of FDU 810 (B) or FDU 810 (C). For example, when the coil 810 of FDU 810 (B) is intersected by the magnetic field and the rectified voltage exceeds the preset threshold voltage, the indicator 824 for FDU 810 (B) will activate.

As this alignment method is followed, the alignment device 800 is repositioned based on the intersection of the magnetic fields with the coils 812 of the FDUs 810 and the subsequent activation of the indicators 824. Next, a third FDU 810 coil 812 will have an increase in voltage. Depending on the movement of the alignment device 800, the next coil 812 to have an increase in rectified voltage will be the coil 812 of either FDU 810 (C) or FDU 810 (D). As previously described, the coil 812 must be located orthogonally from a coil 812 that already has an increased voltage. In this example, coil 812 of FDU 810 (C) or coil 812 of FDU 810 (D) can be activated based on the direction of movement in relation to the alternating magnetic field from the transmitter 210. Therefore, in this embodiment, as shown in FIG. 12, the third coil 812 to activate must be orthogonal to the coil 812 of FDU 810 (A) or FDU 810 (B).

Finally, with three of the four coils 812 intersected by the magnetic field, and their relative indicators 824 activated, the alignment device 800 will now be moved in the average direction of the activated indicators 824. In this embodiment, the alignment device 800 must be moved toward the indicator activated by coil 812 of FDU 810 (A). As shown in FIG. 13, by moving the alignment device 800 in the

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general direction of coil **812** of FDU **810** (A), the coil **812** of FDU **810** (D), will have an increase in rectified voltage. Once the voltages on all coils **812** are equal (or near equal), and all four of the indicators **824** are activated, as shown in FIG. **14**, the alignment device **800** is now at a position where the magnetic field intersecting all four coils **812** is equal (or near equal) in strength. Consequently, this position of the alignment device **800** must be the optimal aligned position at which the maximum coupling coefficient value and the highest wireless power transfer efficiency are achieved.

When the alignment device **800** is in the optimal aligned position, the position can be marked on the material **230** on which the receiver **220** is to be mounted. Marking of the position can be executed with a writing apparatus via through-holes on the alignment device **800**. The through-holes on the alignment device **800** match the coordinates of the mounting points on the receiver **220**. The writing apparatus may be a pencil, pen, marker, etc., or any narrow-ended, pointed or sharp object able to fit in the through-holes of the alignment device **800** to mark or indent the material **230** on which the receiver **220** is to be mounted and aligned with the transmitter **210**.

While a particular FDU has been described, one of reasonable skill in the art will appreciate that other configurations are possible. Turning now to FIG. **15**, another embodiment of an FDU **910** of an alignment device is illustrated. The FDU **910** is generally referred to as a pin diode configuration. In this embodiment, the FDU **910** comprises at least one coil **912**. The coil **912** is identical to previously-described coil **312** unless otherwise stated. The coil **912** is electrically connected to three parallel capacitors **902**, **904**, **906** having capacitances **C1**, **C3** and **C4**, respectively. As with the FDU **310**, the capacitors **904** and **906** are connected to a rectifier formed from a diode **916** (D3) connected in parallel, a diode **918** (D2) connected in series to capacitor **904**, a capacitor **920** connected in parallel between diodes **916** and **918**, and a resistor **922** having a resistance **R** connected in parallel to the capacitor **920**. A voltage at the resistor **922** is given as **Vo**.

The FDU **910** further comprises a diode **930** (D1) connected to the capacitor **902**, and a capacitor **932** having a capacitance **C2** connected to the diode **930**. The diode **930** is connected in parallel to two choke inductors **940**, **942** having inductances of **L1** and **L2**, respectively. Each choke inductor **940**, **942** blocks AC current only and only allows DC current. Each inductor **940**, **942** is connected in series to a resistor **944**, **946**, respectively. Each resistor **944**, **946** is connected in series to a voltage source **950**, **952**, respectively, having a voltage **V1** and **V2**, respectively.

In the illustrated arrangement, diode **930** (D1) is a pin diode. The diode **930** is ON, i.e. current flows through the diode **930**, when voltage **V1** is greater than voltage **V2**, and OFF, i.e. no current flows through the diode **930**, when voltage **V1** is less than voltage **V2**. The diode **930** is used to "switch in" capacitors **902** and **932** to decrease the resonant frequency of the coil **312**.

Capacitance C_A is defined as the cumulative capacitance of capacitors **902**, **932**, **904** and **906** (**C1**, **C2**, **C3** and **C4**) at a frequency f_A , and capacitance C_B is defined as the cumulative capacitance of capacitors **902**, **932**, **904** and **906** (**C1**, **C2**, **C3** and **C4**) at a frequency f_B . In an exemplary embodiment, frequency f_A is equal to 6.78 MHz and frequency f_B is equal to 13.56 MHz. When the diode **930** (D1) is OFF capacitance C_B is achieved and when the diode **930** (D1) is ON capacitance C_A is achieved.

Given the stated frequencies, frequency f_B is equal to twice frequency f_A as expressed in equation (1) as:

$$f_B = 2 * f_A \quad (1)$$

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There is a squared relationship between frequency and capacitance, therefore doubling the frequency results in 4 times the capacitance in the circuit. Accordingly, capacitance C_A is equal to four times the capacitance C_B as expressed in equation (2) as:

$$C_A = 4 * C_B \quad (2)$$

For a given value of capacitance **C4**, capacitance **C3** may be expressed in equation (3) as:

$$C_3 = \frac{C_B C_4}{C_4 - C_B} \quad (3)$$

When capacitance **C1** is equal to capacitance **C2** and the equivalent capacitance C_T is equal to two times capacitance **C1** or **C2**, then the equivalent capacitance C_T may be expressed in equation (4) as:

$$C_T = \frac{C_4 C_3 - C_A (C_4 - C_3)}{C_A - C_4} \quad (4)$$

The equivalent capacitance C_T is the equivalent capacitance of the capacitors **902**, **932** when the diode **930** is ON. Capacitance **C4** is selected to be sufficiently large in order to avoid negative values for capacitance **C3**. Capacitance **C3** is selected to be sufficiently small to allow equivalent capacitance C_T to be positive.

Turning now to FIG. **16**, another embodiment of an FDU **954** of an alignment device is illustrated. The FDU **954** is generally referred to as a metal oxide semiconductor field effect Transistor (MOSFET) configuration. In this embodiment, the FDU **954** comprises at least one coil **956**. The coil **956** is identical to previously-described coil **312** unless otherwise stated. The coil **956** is electrically connected to three parallel capacitors **958**, **960**, **962** having capacitances **C1**, **C2** and **C3**, respectively. As with the FDU **310**, the capacitors **958**, **960** are connected to a rectifier formed from a diode **964** connected in parallel, a diode **966** connected in series to the capacitor **958**, a capacitor **968** connected in parallel between diodes **964**, **966**, and a resistor **970** having a resistance **R** connected in parallel to the capacitor **968**. A voltage at the resistor **970** is given as **Vo**.

The capacitor **962** is connected to a pair of opposing positioned transistors **972**, **974** which are connected to the capacitor **968**. The transistors **972**, **974** are configured to switch the increased capacitance of the capacitor **962** into or out of a resonating circuit of the FDU **954**. The resonating circuit comprises the coil **956** of the FDU **954** and other resonating components, i.e. capacitors **958**, **960**, **962**, **968**.

A resistor **976** is connected in parallel between the transistors **972**, **974**. The resistor **976** is a choke insulator resistor. The choke insulator resistor is connected to ground. The transistors **972**, **974** are configured to prevent an AC signal from bridging across both transistors **972**, **974** in their powered off state. The transistors **972**, **974** are connected at their drains to a voltage source **980** having a voltage **Vc**. The voltage source **980** is an AC voltage source.

The drain of the transistor **972** is connected to the capacitor **962** while the source of the transistor **972** is connected to the source of the transistor **974**. The drain of the transistor **974** is connected to the capacitor **968**. When powered off, the transistors **972**, **974** act as diodes.

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If a single transistor **972** or **974** were present, rather than two transistors **972**, **974**, a sufficiently high voltage (typically over 0.7 volts) would pass through on either the positive or negative waveform of the voltage source **980**.

With two transistors **972**, **974** connected in series, and their diode-like directions reversed, i.e. the source of each transistor **972**, **974** connected to each other, what would have passed through one transistor, will not pass through the other. The resistor **976** maintains a zero reference DC voltage between transistors **972**, **974**.

The relationship between resonating frequency and the inductor/capacitor may be given in equation (5) as:

$$f = \frac{1}{2\pi\sqrt{LC}} \quad (5)$$

where f is the frequency of magnetic field to be detected, L is the inductance of the coil **956**, and C is the capacitance of the resonating circuit of the FDU **954**.

The equivalent capacitance of the resonating circuit when the transistors **972**, **974** are allowing current to flow is given by C_{low} . The equivalent capacitance of the resonating circuit when the transistors **972**, **974** are not allowing current to flow is given by C_{high} . In low frequency use cases, the capacitance (C_{fet}) of each transistor **972**, **974** is negligible and may be ignored. The required inductance of the coil **956** and the capacitances **C1**, **C2**, **C3** of the capacitors **956**, **960**, **962**, respectively, may be calculated accordingly for a given frequency, e.g. 6.78 MHz.

Turning now to FIG. 17, another embodiment of an alignment device generally identified by reference numeral **1000**. The alignment device **1000** comprises all of the elements of the previously described alignment device **300** unless otherwise stated. Similarly, the alignment device **1000** functions similarly to the previously described alignment device **300** unless otherwise stated. The alignment device **1000** comprises five coplanar FDUs **1010**. Each FDU **1010** comprises a coil **1012**, at least one tuning capacitor **1014** and a rectifier **1016**. Thus, the alignment device **1010** comprises five coils **1012**, five tuning capacitors **1014**, and five rectifiers **1016**. Each of the five coils **1012** is electrically connected to a different tuning capacitor **1014**. Each of the five tuning capacitors **1014** is electrically connected to a different rectifier **1016**. Each FDU **1010** is electrically connect to the main board (not shown). The main board of the alignment device **1000** is identical to the previously described main board **318** unless otherwise stated. Each rectifier **1016** of each FDU **1010** is electrically connected to the voltage divider **320** of the main board **318**.

In this embodiment, the FDUs **1010** are orthogonally positioned in respect to each other. Two FDUs **1010** (indicated by the letters B and D) are coplanar and positioned in the X-Y plane with two FDUs **1010** opposite to, and laterally spaced from, each other along the X-axis, and equidistant to a central FDU **1010** (indicated by the letter C). The two other FDUs **1010** (indicated by the letters A and E) are opposite to, and laterally spaced from, each other orthogonally along the Y-axis, and equidistant to the central FDU **1010** (C).

The coils **1012** are positioned at fixed distances from each other to detect the strength of AC magnetic field generated by the transmitter **210**. The value of the detected magnetic field strength at each coil **1012** is used to determine the optimal alignment position.

As illustrated in FIG. 17, the alignment device further comprising a control and logic module **1050**. Similar to

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alignment devices **300** and **800**, the alignment device **1000** comprises the main board which, in the illustrated embodiment, is incorporated in the module **1050**. The main board **318** comprises a voltage divider **320**, a comparator **322**, which in this embodiment takes the form of a comparator circuit, a sensitivity control **323** and indicators **324**. In the illustrated embodiment, the main board comprises five indicators, each indicator associated with an FDU **1010** of the alignment device **1000**. The main board and the components comprised thereon are identical to the previously described main board and components comprised thereon. In this embodiment, the indicators are LEDs. In this embodiment, the sensitivity control **323** is a turnable knob, dial or the like. The module **1050** may further comprise a microcontroller, microprocessor, computer or any other computing means. The module **1050** may further comprise a suitable storage means, e.g. computer-readable memory, and one or more processors.

The module **1050** is configured to analyze field strength in two directions: vertical and horizontal. In one embodiment, the module **1050** receives voltages detected at the FDUs **1010**. The module **1050** analyzes the received voltages and controls indicators associated with the FDUs **1010**. In particular, the module **1050** controls one or more LEDs to operate, light up, continuously or in a repeating pattern. The module **1050** may control the time between an LED turning on and off. The module **1050** controls an indicator to stay off until controlled to operate, e.g. turn on.

In the illustrated arrangement, the field is the magnetic field. The module **1050** is configured to analyze field strength in the vertical direction and the horizontal direction independent of each other. Magnetic field data collected from the FDUs **1010** (B, C, D) form horizontal field data. Magnetic field data collected from the FDUs **1010** (A, C, E) form vertical field data. The collected horizontal and vertical field data is analyzed at the module **1050**.

When the center FDU **310** (C) detects the highest voltage compared to all detected voltages at its associated coil **1012**, the alignment device **1000** is aligned with the transmitter **210** and the optimal position of a receiver is determined.

In use, the alignment device **1000** is positioned within a two-dimensional plane (X-Y plane) which has a fixed orthogonal distance from the plane of the transmitter **210** and associated transmitter coil **212**. The orthogonal distance is determined by the thickness of the material **230** separating the alignment device **1000** from the transmitter **210**. As the material **230** has a uniform thickness, the two-dimensional planes of the alignment device **1000** and the transmitter **210** are parallel to each other.

Initially the FDUs **1010** detect voltages at various frequencies, e.g. two frequencies at 6.78 MHz and 13.56 MHz, to determine at which frequency the detected voltages are higher. Based on the higher detected voltage, the module **1050** determines which frequency the transmitter **210** is operating at and controls the FDUs **1010** to detect voltages at this frequency.

Comparisons between voltages are based off a running average of the voltage at each coil **1012** of the FDUs **1010** to avoid choppy LED operations.

If no voltage is detected, the alignment device **1000** stops detecting voltage for a predetermined amount of time or until a user instructs the alignment device **1000** to again detect voltages to preserve power. In this configuration, the alignment device **1000** is in a standby mode. The standby mode is indicated by one LED on each FDU **1010** being lit at a time in a clockwise pattern.

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Once the module **1050** has determined the frequency at which the transmitter **210** is operating, all five FDUs **1010** collect voltages and these are transferred to the module **1050**. As described above, the module **1050** separately analyzes horizontal and vertical data.

The module **1050** determines from the horizontal field data (from FDUs **1010** B, C, D) and vertical field data (from FDUs **1010** A, C, E) in which direction the center of the magnetic field is located. If the alignment device **1000** is significantly misaligned and the direction cannot be determined, the LEDs associated with the FDUs **1010** blink along the misaligned direction.

As shown in FIG. **18**, the alignment device **1000** may be in different regions prior to being in optimal alignment. Specifically, the alignment device **1000** may be in an outer region (low proximity) **1064**, inner region (mid proximity) **1062** and aligned spot **1060**. The aligned spot **1060** corresponds to an area within which optimal alignment with the transmitter **210** is achieved.

As the alignment device **1000** approaches alignment from far away, the alignment device is in the outer region (low proximity) **1064**. In this outer region **1064** one LED associated with the FDUs **1010** is lit to indicate where the center of the magnetic field (and alignment), i.e. spot **1060**, is located, and accordingly in which direction the device **1000** should be moved. When the alignment device **1000** enters the inner region (mid proximity) **1062**, the LED facing away from the spot **1060** begins to blink at a low frequency, increasing in frequency as the device **1000** approaches the spot **1060** and optimal alignment. When the alignment device **1000** is aligned at the spot **1060** in optimal alignment, both of the aforementioned LEDs remain ON with no blinking.

This process may be performed separately for both vertical and horizontal alignment, or performed simultaneously for both vertical and horizontal alignment.

In a particular embodiment, if the alignment device **1000** has not detected a significant magnetic field for a specified period of time, the alignment device **1000** may power down. The alignment device **1000** may power on after a period of time or upon activation by a user as previously described.

Although a particular configuration of the previously described main boards **310** and **810** has been described, one of skill in the art will appreciate that other configurations are possible. Turning now to FIG. **19**, a block diagram of another embodiment of an alignment device generally identified by reference numeral **1300**. The alignment device **1300** comprises all of the elements of the previously described alignment device **300** unless otherwise stated. In this embodiment, the main board **1318** comprises a voltage divider **1320**, an analog-to-digital (A/D) converter **1326**, a microcontroller **1328**, a sensitivity control **1323** and one or more indicators **1324**. The voltage divider **1320** is electrically connected to the rectifier **1316** of the FDU **1310**. The voltage divider **1320** is also electrically connected to the A/D converter **1326**. The A/D converter **1326** is electrically connected to the voltage divider **1320** and to the microcontroller **1328**. The sensitivity control **1323** is connected to the microcontroller **1328**. One of reasonable skill in the art will appreciate that the microcontroller **1328** may take the form of a computer. Furthermore, one of reasonable skill in the art will recognize that the microcontroller **1328** could easily be replaced with a microprocessor **328**. One of reasonable skill in the art will recognize that multiple FDUs **1310** attached to one main board **1318** is possible, and as such, multiple indicators **1324** are also possible.

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The voltage divider **1320** is configured to scale down the rectified voltage from the rectifier **1316**. The A/D converter **1326** is configured to convert the analog voltage from the voltage divider **1320** into a digital voltage signal. The digital voltage signal is then processed by the microcontroller **328**. Specifically, the digital voltage signal is fed into the microcontroller **1328**, where the comparison of the digitized voltage against the preset threshold voltage is compared using software algorithms rather than a hardware comparator circuit **322**. When the digital voltage signal exceeds the preset threshold voltage, the microcontroller **1328** is configured to signal the indicator(s) **1324** to activate. Specifically, the microcontroller **1328** activates the indicator(s) **1324** when the rectified voltage exceeds the threshold voltage.

While alignment devices have been described, one of skill in the art will appreciate that other configurations are possible. In another embodiment, any of the described alignment devices may further comprise a spirit level. The spirit level (also known as a bubble level or level) may improve ease of use of the alignment device. In this embodiment, the spirit level is a generally cylindrical and plastic although other shapes and materials are possible.

The spirit level ensures level installation of both the transmitter coil **212** and the receiver coil **222**. Incorporating the spirit level into the alignment device may reduce the number of tools and personnel required to align the transmitter and receiver coils **212** and **222**, respectively, as described.

While particular use cases of the described alignment devices have been described, one of reasonable skill in the art will appreciate that other use cases are possible. In particular, any of the described alignment devices may be used to create a spatial distribution of the detected magnetic field. In this embodiment, the alignment device further includes an accelerometer to measure the acceleration of the device. Detected voltages from the coils of all of the FDUs are combined with the acceleration data collected by the accelerometer to produce a spatial distribution of the magnetic field.

An exemplary spatial distribution diagram of a detected magnetic field is illustrated in FIG. **20A**. As illustrated in FIG. **20A**, the central spot **1100** in the diagram indicates the position of optimal alignment.

There may be cases where the spatial distribution diagram may be distorted, for example, when a metallic object like a wire bundle or mesh is present in the detection area. In this case the spatial distribution diagram may show a "magnetic footprint". FIG. **20B** illustrates such a magnetic footprint as a footprint of a wire bundle **1102** on the spatial distribution diagram. FIG. **20C** illustrates another magnetic footprint as a footprint of a metallic mesh **1104**.

One of reasonable skill in the art will recognize that the alignment device **300** can be separate or part of the receiver **220**. When the alignment device **300** is part of, or built into the receiver **220**, there is no requirement for marking the position via through-holes, for example, as aligning the alignment device, simultaneously aligns the receiver in the optimal position for the most efficient transfer of power from the transmitter **210** to the receiver **220**.

While particular alignment devices have been described, one of skill in the art will appreciate that other configurations are possible. In another embodiment, the described alignment devices further comprise controls and/or logic configured to apply certain logic to signals within the alignment device and control the alignment device. In one embodiment, controls and logic comprise a microprocessor, micro-

controller, display, speaker, touchpad, button, knob, switch or other types of controls and logic elements.

While the alignment devices described comprise one or more coils and are configured for use in generating an induced voltage from a magnetic field, one of reasonable skill in the art will appreciate that other configurations are possible. In another embodiment, each FDU of the described alignment devices comprises an electrode as opposed to a coil. Furthermore, in this embodiment, each FDU comprises at least one tuning coil as opposed to at least one tuning capacitor. The tuning coil is configured to tune the electrode to the resonant frequency of the transmitter. The electrode of the alignment device is configured to generate an induced voltage from an electric field in order to determine the position of the alignment device in relation to the transmitter or transmitter coil of a wireless power transfer system. The electrode may take the form of any of the electrodes described in U.S. Pat. No. 10,424,942, the relevant portions of which are incorporated herein.

While optimal alignment has been described with respect to the transmitter **210** comprising the transmitter coil **212**, and the receiver **220** comprising the receiver coil **222**, one of reasonable skill in the art will appreciate that other configurations are possible. In another embodiment, the transmitter **210** comprises one or more capacitive electrodes, and the receiver **220** comprises one or more capacitive electrodes. The described alignment device determines the optimal alignment of the transmitter **210** and receiver **220** to achieve the maximum coupling coefficient value and hence, the highest power transfer efficiency. The transmitter capacitive electrodes and receiver capacitive electrodes are in optimal alignment when their centre axes normal to the transmitter capacitive electrodes and the receiver capacitive electrodes are collinear. The centre axis of each of capacitive electrode is the axis extending through the centre of mass of the respective capacitive electrode. Respective capacitive electrodes of the transmitter **210** and receiver **220** are in optimal alignment when the centre axes normal to both respective capacitive electrodes are collinear.

While the alignment devices described have been described in respect of a high frequency wireless power transfer, one of reasonable skill in the art will appreciate that other the alignment devices may be used in other wireless power systems. In another embodiment, the described alignment devices are configured for use in a wireless power system that is not high frequency.

One of reasonable skill in the art will also recognize that while the example alignment device **300** disclosed is designed for use with a high frequency inductive wireless power transfer system **200**, it is also possible to apply the same concepts to create an alignment device **300** that will work other wireless power transfer systems **200**, such as, but not limited to, non-resonant magnetic induction systems, resonant magnetic induction systems, non-resonant electric capacitive systems, resonant electric capacitive systems, low frequency magnetic induction or electric capacitive systems.

Those of skill in the art will appreciate that further variations and modifications may be made without departing from the scope of the appended claims.

What is claimed is:

1. An alignment device, comprising:

- a coil configured to generate an induced voltage from a magnetic field, or an electrode configured to generate an induced voltage from an electric field; and
- a comparator configured to compare the induced voltage to a threshold voltage and activate an indicator based on the comparison,
- the coil or electrode forming part of a field detection unit (FDU), and
- the FDU including at least one diode configured to add capacitors to the coil to decrease a resonant frequency of the coil.

2. The alignment device of claim **1**, wherein the induced voltage is proportional to a strength of the magnetic field intersecting the coil, or to the electric field intersecting the electrode.

3. The alignment device of claim **1**, wherein the alignment device is configured to align a transmitter and a receiver for optimal power transfer efficiency.

4. The alignment device of claim **1**, wherein the alignment device is configured to align a transmitter coil and a receiver coil for optimal power transfer efficiency.

5. The alignment device of claim **1**, wherein the alignment device is configured for use with a high frequency wireless power transfer system.

6. The alignment device of claim **1**, wherein the FDU comprises at least one tuning capacitor configured to tune the coil.

7. The alignment device of claim **1**, wherein the FDU comprises a rectifier configured to rectify the induced voltage from alternating current (AC) to direct current (DC).

8. The alignment device of claim **1**, wherein the alignment device comprises a plurality of FDUs, each FDU comprising an individual coil configured to generate an induced voltage from a magnetic field, or an individual electrode configured to generate an induced voltage from an electric field.

9. The alignment device of claim **8**, wherein the alignment device comprises four FDUs orthogonally positioned with respect to each other in a plane.

10. The alignment device of claim **9**, wherein the FDUs are positioned equidistant to each other in the plane.

11. The alignment device of claim **8**, wherein the alignment device comprises five FDUs orthogonally positioned with respect to each other in a plane.

12. The alignment device of claim **11**, wherein four FDUs are positioned equidistant to a central FDU in the plane.

13. The alignment device of claim **1**, wherein each FDU is associated with an individual indicator.

14. The alignment device of claim **1**, wherein the comparator forms part of a main board.

15. The alignment device of claim **14**, wherein the main board further comprises at least one of the indicator, a voltage divider configured to scale down voltage, and a sensitivity control configured to control the threshold voltage.

16. The alignment device of claim **1**, further comprises a spirit level.

17. The alignment device of claim **1**, wherein the comparator is configured to compare the induced voltage to the threshold voltage and activate the indicator based on the induced voltage exceeding the threshold voltage to indicate alignment.