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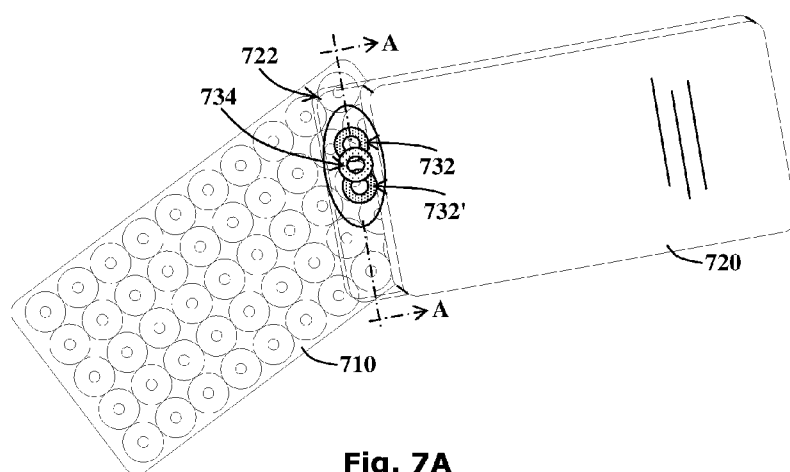
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(54) **Title:** SYSTEM AND METHODS FOR POWER COUPLING USING COILS ARRAY

**Fig. 7A**

(57) **Abstract:** A wireless power coupling arrangement comprising at least one wireless power transmitter; the power transmitter comprising an array of primary coil shielded behind an insulating layer for inductive coupling to a wireless power receiver; said power receiver comprising a secondary coil wherein said insulating layer is substantially flat. The secondary coils and the primary coils differ in size such that the primary coil is smaller than the secondary in a ratio of 2/3 up to 1/4, to reduce energy loss and increase efficiency. Additionally or alternatively, the wireless power receiver comprising at least two overlapping secondary coils to eliminate black spot causing energy loss.



## SYSTEM AND METHODS FOR POWER COUPLING USING COILS ARRAY

## FIELD OF THE INVENTION

The present disclosure relates wireless power systems for providing a wireless  
5 power transfer between wireless power transmitters and wireless power receivers. In particular, the disclosure relates to multi-coil surfaces, substantially flat, comprising coil arrays for efficient wireless power transmission to electrical devices via associated wireless power receivers.

## BACKGROUND

10 The use of a wireless non-contact system for the purposes of automatic identification or tracking of items is an increasingly important and popular functionality.

Wireless power coupling allows energy to be transferred from a power supply to an electric load without a wired connection therebetween. An oscillating electric  
15 potential is applied across a primary coil. An oscillating magnetic field in the vicinity of the primary coil may induce a secondary oscillating electrical potential in a secondary coil situated nearby. In this way, electrical energy may be transmitted from the primary coil to the secondary coil by electromagnetic induction without a conductive connection between the inductors.

20 When electrical energy is transferred from a primary coil to a secondary coil, the coils are said to be wirelessly coupled. An electric load wired in series with such a secondary coil may draw energy from the power source wired to the primary inductor when the secondary coil is inductively coupled thereto.

Various approaches have been sought to improve wireless power transfer  
25 losses, power transfer efficiency and power transfer ranges, potentially by using higher frequencies, optimized drive electronics and the like.

Electrical power transmission systems allowing a power receiving electrical device to be placed anywhere upon an extended base unit covering a larger area have been proposed in various cases. These provide freedom of movement without  
30 requiring the trailing of wires. One such example is described in United States Patent No. 7,164,255 to Hui. In Hui's system a planar inductive battery charging system is designed to enable electronic devices to be recharged. The system includes a planar

charging module having a charging surface on which a device to be recharged is placed. Within the charging module, and parallel to the charging surface, is at least one, and preferably an array of primary windings that couple energy inductively to a secondary winding formed in the device to be recharged. Hui's system also provides  
5 secondary modules that allow the system to be used with conventional electronic devices not supplied with secondary windings.

Furthermore, United States Patent No. 6,803,744, to Sabo, titled "Alignment independent and self-aligning inductive power transfer system" describes an inductive power transfer device for recharging cordless appliances. It also addresses the  
10 problem of wirelessly aligning a secondary coil to a primary coil. Sabo's device includes a plurality of coils arranged in an array and connected to a power supply via switches which are selectively operable to activate the respective inductors. The secondary coil of the transformer is arranged within the appliance. When the appliance is positioned proximate to the power transfer device with the respective  
15 coils in alignment, power is inductively transferred from the device to the appliance via the transformer.

Nevertheless the need remains for an efficient, cost effective and a wireless power coupling mechanism which may not require exact coil alignment. The present invention addresses this need.

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## SUMMARY OF THE INVENTION

According to various embodiments a wireless power transmitter is introduced for transferring power wirelessly to at least one electric load via a wireless power receiver. The wireless power transmitter includes: a multi-coil power transmission surface comprising an array of primary coils for wirelessly coupling with at least one secondary coil of the wireless power receiver located in front of said multi-coil power transmission surface, and wherein the array of primary coils comprises primary coils having diameters selected to be smaller than the diameter of the secondary coil such that when a secondary coil is placed over the multi-coil power transmission surface at secondary coil.

Where appropriate, the wireless power transmitter further comprising a driver wired to a power source and operable to drive each primary coil of the array.

Optionally, each primary coil of the array of primary coils is independently connected to the power source via the at least one driver.

Optionally, the wireless power transmitter includes a plurality of drivers, each driver being wired to a power source and operable to drive a cluster of primary coils.

Optionally, the diameter of the primary coil is selected such that the ratio between the diameter of the secondary coil and the diameter of the primary coils is above three halves.

Optionally, the diameter of the primary coil is selected such that the ratio between the diameter of the secondary coil and the diameter of the primary coils is above four.

Optionally, the diameter of said primary coil is selected such that the ratio between the diameter of the secondary coil and the diameter of the primary coils is above three halves and below four.

Optionally, each primary coil of the array of primary coils is spaced in the multi-coil power transmission surface at an inter-coil spacing distance and the inter-coil spacing distance is zero.

Optionally, each primary coil of the array of primary coils is spaced in the multi-coil power transmission surface at an inter-coil spacing distance and the inter-coil spacing distance is less than half of the secondary coil size.

Optionally, each primary coil is vertically offset from the secondary coil by a distance less than 14 millimeters.

Where appropriate, the array of primary coils of the wireless power coupling system are shielded by an insulating layer. Furthermore, the insulating layer is  
5 constructed from a material selected from at least one member of the group consisting of: glass, plastic mica, formica, wood, wood veneer, canvas, cardboard, stone, linoleum, paper and combinations thereof.

Optionally, the secondary coil is not circular and the primary coils have diameters selected to be smaller than the major axis of the secondary coil.

10 Optionally, the secondary coil is not circular and the primary coils have diameters selected to be no larger than two thirds of the major axis of the secondary coil.

According to a further aspect of the disclosure is presented of a wireless power receiver for receiving power wirelessly from a wireless power transmitter. The  
15 wireless power receiver includes: at least a first secondary coil and a second secondary coil, each secondary coil for wirelessly coupling with at least one primary coil of the wireless power transmitter; wherein the first secondary coil overlaps the second secondary coil.

Optionally, the first secondary coil and the second secondary coil are offset by a  
20 distance which is less than half of the diameter of each secondary coil.

Where appropriate, the wireless power transmitter comprises an array of primary coils and the first secondary coil and the second secondary coil are offset by a distance which is at least half the inter-coil spacing of primary coils within the array.

Where appropriate, wherein at least one of said first secondary coil and the  
25 second secondary coil is configured to align with at least one primary coil at any angle such that the wireless power receiver is rotatable through 360 degrees.

Where appropriate, the wireless power receiver further comprising a power cord for connecting to at least one electric load.

Where appropriate, the wireless power receiver further comprising a receiver  
30 coil selector operable to select one of at least first secondary coil and the second secondary coil to connect to an electric load.

Optionally, the first secondary coil and said second secondary coil are connected in parallel to an electric load.

### BRIEF DESCRIPTION OF THE FIGURES

5 For a better understanding of the invention and to show how it may be carried into effect, reference will now be made, purely by way of example, to the accompanying drawings.

With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of  
10 the preferred embodiments of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is  
15 the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice. In the accompanying drawings:

Fig. 1 is a block diagram showing the main elements of a wireless power transfer system incorporating a signal transfer system;

Fig. 2A is a block diagram schematically representing the main features of a  
20 wireless power transfer system according;

Fig. 2B is a schematic representation of a wireless power coupling consisting of a wireless power transmitter and a wireless power receiver according to another embodiment of the present invention;

Figs. 3A-C show three exemplary receiver-mounted visual alignment  
25 mechanisms for a wireless power coupling;

Fig. 4A shows a power surface including an array of wireless power transmitters in accordance with yet another embodiment of the invention;

Fig. 4B shows two movable wireless power receivers lying upon the power surface of Fig. 4A;

30 Fig. 4C shows a power receiver provided with two secondary coils for coupling with primary coils of the power surface of Fig. 4A;

Figs. 5 shows an exemplary applications of the power surface of Fig. 4A providing power to a computer.

Fig. 6A shows a wireless power transfer system wherein the primary and secondary coils have differing coil sizes at a determined ratio;

5        Fig. 6B shows a wireless power transfer system wherein multiple overlapping coils are provided in the wireless power receiver;

Figs. 6C show block diagrams of various possible configurations for connecting and array of secondary coils to an electric load in embodiments of a multiple coil wireless power receiver;

10        Fig. 7A shows a possible overlapping secondary coil receiver connected to an electric mobile device and configured to draw power from a multi-coil surface;

Fig. 7B shows a cross section of the rectangular overlapping secondary coil add-on as illustrated in Fig. 7A;

15        Figs. 8A-C illustrate various possible driving configurations for primary coils in a multi-coil surface array;

Fig. 9A is a schematic representation of a signal transfer system incorporated into a system for locating secondary coils placed upon a multi-coil power transmission surface; and

20        Fig. 9B is a schematic representation of a possible signal transfer system for locating a power receiver having placed upon a multi-outlet power transmission surface.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

It is noted that the systems and methods of the disclosure herein may not be limited in their application to the details of construction and the arrangement of the components or methods set forth in the description or illustrated in the drawings and examples. The systems and methods of the disclosure may be capable of other  
5 embodiments or of being practiced or carried out in various ways. Alternative methods and materials similar or equivalent to those described herein may be used in the practice or testing of embodiments of the disclosure. Nevertheless, particular methods and materials are described herein for illustrative purposes only. The materials,  
10 methods, and examples are not intended to be necessarily limiting. It is further noted that in order to implement the methods or systems of the disclosure, various tasks may be performed or completed manually, automatically, or combinations thereof.

Aspects of the current disclosure relates to efficient power transmission systems providing wireless from a wireless power transmitter to a wireless power receiver power efficiently to overcome wireless power transfer losses and decreased  
15 power transfer efficiency. The wireless power receiver, connected to an electrical load such as a mobile device, is operable to wirelessly couple with a multi-coil array, embedded in a substantially flat surface. In some embodiments the wireless power transmitter comprises ultra-thin coil arrays for wireless power transmission. The  
20 disclosure provides solutions, to enable high efficiency power transfer with minimal need for coil alignment. In particular, embodiments with different sizes for primary and secondary coils are used, avoiding areas of low transmission, or black spots over wireless power transfer surface.

The current disclosure further describes a wireless transmitter comprising a  
25 coil array, with a varying number of primary coils which may be embedded in a surface (in the surface / under the surface) which may provide thin solutions. In particular, the primary coil size of the wireless power transmitter may be smaller than the size of the secondary coil of the wireless power receiver. Various ratios between the diameter of the primary coils to the diameter of the secondary coils are suggested  
30 such as  $2/3$ ,  $1/4$ ,  $1/2$  and the like.

It is noted that such coil size ratios may prevent any black spot that reduces wireless power energy transfer.

Additionally or alternatively, the current solution may provide a better optimized wireless power receiver solution and may be further configured to support existing wireless power receivers. Furthermore, such wireless power transmitter/power receiver coil size relationships may reduce magnetic field leakage to a foreign object, which may cause a Foreign Object Detection (FOD) event. An FOD event is commonly caused when transmitted magnetic field generates heat due to “eddy currents” within metallic objects closely located to the wireless power receiver associated with the device. The FOD event may cause efficiency degradation, which may potentially lead to safety accidents.

10 Additionally, such FOD events are of great concern in systems with relatively large wireless power transmitter coils (power transmitter coil is relatively larger than power receiver coil). In such cases the power transmitter may possibly be covered by the receiver as well as other unintended metallic objects such as keys, coins, paper clips and the like. The suggested topology may resolve this problem as a power receiver coil fully covering the power transmitter coil may minimize the magnetic leakage and may physically prevent any other object to be placed over the active power transmitter coil.

Additionally or alternatively, the secondary coil of the wireless power receiver may use a rectangular shape and may fit as an add-on to a mobile device.

20 *Description of the Embodiments:*

Reference is now made to Fig. 1 showing a block diagram 10 of the main elements of a wireless power coupling 20A incorporating a signal transfer system 10A according to a first embodiment of the invention;

The inductive power coupling 20A consists of a primary inductive coil 22 and a secondary inductive coil 26. The primary coil 22 is wired to a power supply 24 typically via a driver 23 which provides the electronics necessary to drive the primary coil 22. Driving electronics may include a switching unit providing a high frequency oscillating voltage supply, for example. The secondary coil 26 is wired to an electric load 28.

30 When the secondary coil 26 is brought into proximity with the primary coil 22, the pair of coils forms an inductive couple and power is transferred from the primary

coil 22 to the secondary coil 26. In this way a power outlet 20 may provide power to an electric device 30.

The signal transfer system 10A comprises: a signal generator 12, for generating a control signal  $S_C$ ; a transmitter 14 for transmitting said control signal  $S_C$ ;  
5 and a receiver 16 for receiving said control signal  $S_C$ .

Although in the signal transfer system 10A described herein, the transmitter 14 is incorporated into the power outlet 20 and the receiver 16 is incorporated into the electrical device 30, it will be appreciated that a transmitter 140 may alternatively or additionally be incorporated into the electrical device 30 and a receiver 16 may  
10 alternatively or additionally be incorporated into the power outlet 20.

The control signal  $S_C$  communicates encoded data pertaining to the power transmission. This data may be pertinent to regulating efficient power transmission. Examples of such data includes parameters such as: required operating voltage, current, temperature or power for the electric load 28, the measured voltage, current,  
15 temperature or power supplied to the electric load 28 during operation, the measured voltage, current, temperature or power received by the electric load 28 during operation and the like.

In other embodiments, the control signal  $S_C$  may communicate data relating to the coordinates of the primary inductive coil 22 for the purposes of indicating the  
20 location of the power outlet 20. Alternatively, the control signal  $S_C$  may communicate data relating to the identity or presence of the electric load 28 such as the location of the secondary coil 26, or an identification code or the electric device 30 or its user.

Various transmitters 14 and receivers 16 may be used with the signal transfer system. Where the primary and secondary coils 22, 26 are galvanically isolated for  
25 example, optocouplers may have a light emitting diode serving as a transmitter 14 which sends encoded optical signals over short distances to a photo-transistor which serves as a receiver 16. Optocouplers typically need to be aligned such that there is a line-of-sight between transmitter and receiver. In systems where alignment between the transmitter 14 and receiver 16 may be problematic, optocoupling may be  
30 inappropriate and alternative systems may be preferred such as ultrasonic signals transmitted by piezoelectric elements or radio signals such as Bluetooth, WiFi and the like. Alternatively the primary and secondary coils 22, 26 may themselves serve as the transmitter 14 and receiver 16.

Reference is now made to Fig. 2A, a block diagram illustrating a wireless power transfer system 200A for wirelessly providing power to an electric load 140, according to one embodiment of the invention. The wireless power transfer system 200A includes a wireless power coupling 100, an alignment mechanism 200 and a power regulator 300.

The wireless power coupling 100 comprises a wireless power transmitter 110 and a wireless power receiver 120. The wireless power transmitter 110 includes a primary inductive coil 112 wired to a power supply 102 via a driving unit 104. The wireless power receiver 120 includes a secondary inductive coil 122 which is wired to the electric load 140. When the secondary coil 122 is brought close to the primary coil 112 and a variable voltage is applied to the primary coil 112 by the driving unit 104, power may be transferred between the coils by electromagnetic induction.

The alignment mechanism 200 is provided to facilitate aligning the primary coil 112 with the secondary coil 122 which improves the efficiency of the inductive coupling. The regulator 300 provides a communication channel between the wireless power receiver 120 and the wireless power transmitter 110 which may be used to regulate the power transfer.

The various elements of the wireless power transfer system 200A may vary significantly between embodiments of the present invention. A selection of exemplary embodiments are described hereinafter in a non-limiting manner.

### **Wireless Power Coupling**

Reference is now made to Fig. 2B, illustrating a wireless power coupling 100 according to one embodiment of the invention. A wireless power transmitter 110, which may be incorporated into a substantially flat surface 130 for example, is couplable with a wireless power receiver 120. The wireless power transmitter 110 includes an annular primary coil 112 shielded behind an insulating layer, which may be hardwired to a power source 102 via a driving unit 104. Driving electronics may include a switching unit providing a high frequency oscillating voltage supply, for example.

The wireless power receiver 120 includes an annular secondary coil 122 that is configured to wirelessly couple with the primary coil 112 of the wireless power transmitter 110 to form a power transferring couple that is essentially a transformer.

Optionally, a primary ferromagnetic core 114 is provided in the wireless power transmitter 110 and a secondary ferromagnetic core 124 is provided in the wireless power receiver 120 to improve energy transfer efficiency.

It will be appreciated that known pinned power couplings of the prior art cannot be readily incorporated into flat surfaces. The nature of any pinned coupling is that it requires a socket into which a pin may be inserted so as to ensure power coupling. In contradistinction, the wireless power coupling 100 of the embodiment of the invention has no pin or socket and may, therefore, be incorporated behind the outer face of a flat surface 130, such as a wall, floor, ceiling, desktop, workbench, kitchen work surface, shelf, door or the like, at a location where it may be convenient to provide power.

It is specifically noted that because the primary coil 112 of the second embodiment is annular in configuration, alignment of the primary coil 112 to the secondary coil 122 is independent of the angular orientation of the wireless power receiver 120. This allows the wireless power receiver 120 to be coupled to the wireless power transmitter 110 at any convenient angle to suit the needs of the user and indeed to be rotated whilst in use.

For example, a visual display unit (VDU) may draw its power via a wireless power receiver 120 of the second embodiment aligned to a wireless power transmitter 110 of the second embodiment incorporated into a work desk. Because of the annular configuration of the coils 112, 122, the angle of the VDU may be adjusted without the wireless coupling 100 being broken.

Prior art inductive coupling systems are not easily rotatable. For example, in order to achieve partial rotation, the system described in United States Patent No. 6,803,744, to Sabo, requires the coils to be connected by flexible wires or brushes to concentric commutators on the body of a non-conductive annular container. Even so, Sabo's system allows rotation of only about half the inter-coil angle. In contradistinction, the wireless power receiver 120 of the second embodiment of the present invention may be rotated through 360 degrees or more, about the central axis of the annular primary coil 110 whilst continually maintaining the power coupling 100.

It is known that inductive energy transfer is improved considerably by the introduction of a ferromagnetic core 114, 124. By optimization of the coupling 100,

appropriate electrical loads, such as standard lamps, computers, kitchen appliances and the like may draw power in the range of 10W – 200W for example.

Various exemplary applications of the wireless power transmitter 110 of Fig. 2B, may be applicable to various devices such as a computer, activating a light bulb and the like.

### Alignment Mechanisms

The efficiency of the power coupling 100, depends upon the alignment between the secondary coil 122 of the wireless power receiver 120 and the primary coil 112 of the wireless power transmitter 110. Where the substantially flat surface 130 is fabricated from transparent material such as glass or an amorphous plastic, such as PMMA for example, the user is able to see the wireless power receiver 120 directly and may thus align the wireless receiver 120 to the wireless transmitter 110 by direct visual observation. However, where the substantially flat surface 130 is opaque alternative alignment mechanisms 200 may be necessary. Such alignment mechanisms 200 may include tactile, visual and/or audible indications, for example.

The details of the visual alignment mechanism are brought hereinafter, as described in Figs. 3A-C by way of example, in a non-limiting manner. It is noted that additional alignment mechanisms may exist such as mechanical alignment mechanism, optical alignment mechanism and more.

### Visual Alignment Mechanisms

Reference is now made to Figs. 3A-C, illustrating exemplary visual alignment mechanisms for a wireless power receiver 120. Figs. 3A-C show a wireless power receiver 120 having a first visual indicator 250 consisting of two indicator LEDs: a rough alignment indicating orange LED 252 and fine alignment indicating green LED 254. A wireless power transmitter 110 is concealed beneath an opaque surface 130. Fig. 3A shows the wireless power receiver 120 at a large distance from the wireless power transmitter 110 with neither of the two indicator LEDs being activated. Fig. 3B shows the wireless power receiver 120 partially aligned with the wireless power transmitter 110 and the orange indicator LED 252 being lit up. This alerts a user that the receiver 120 is in proximity with a wireless power transmitter 110, but is not properly aligned therewith.

By their nature, LEDs are either illuminated or not illuminated, however proximity data may be encoded by flashing, frequency or the like. The intensity of power supplied to other types of indicator lamps may be used to indicate the degree of coupling, or a flashing indicator lamp may be provided, such that the frequency of flashing is indicative of degree of alignment. Indeed, where the load is an incandescent light source or the like, it may be used directly for alignment purposes, since poor alignment results in a noticeable dimming affect.

### Multi-coil Systems

Alignment of a wireless power receiver to a wireless power transmitter may be facilitated by using a plurality of wireless coils and thereby increasing the number of alignment locations.

A plurality of wireless power transmitters 110a-n are shown in Fig. 4A arranged into a wireless power array 1100 covering an extended surface 1300 according to still a further embodiment of the invention. The wireless surface power array 1100 allows for a wireless power receiver 120 to be aligned with a wireless power transmitter 110 in a plurality of locations over the surface 1300. It is noted that although a rectangular arrangement is represented in Fig. 4A, other configurations such as a hexagonal close packed arrangement, for example, may be preferred. Optionally multiple layers of overlapping power transmitters 110 may be provided. Since a power receiver may be placed in alignment with any of the power transmitters 110a-n, a power supplying surface may be provided which can provide power to a wireless power receiver 120 placed at almost any location thereupon, or even to a receiver in motion over the wireless power array 1100.

Reference is now made to Fig. 4B, illustrating two wireless power receivers 120A, 120B lying upon a single wireless power array 1100 including a plurality of embedded wireless power transmitters. The wireless power receivers 120A, 120B are free to move parallel to the surface 1300 as indicated by the arrows. As a wireless power receiver 120, moving along the power array 1100, approaches a wireless power transmitter 110, an anchor 214 associated with the 120 couples with a snag 212 associated with a transmitter 110 so bringing the primary coil 112 into alignment with a secondary coil 122.

When a power receiver 120A lies between two transmitters 110k, 110l, its anchor 214a is not engaged by any snag 212. Consequently, the secondary coil 122A

of the power receiver 120A is not aligned with any primary coil 112. In such a situation an orange LED indicator 252A for example, may be used to indicate to the user that the receiver 120A is close to but not optimally aligned with a primary coil 112. Where a power receiver 120B lies directly in line with power transmitter 110b such that its anchor 214B is engaged by a snag 212b embedded in the power transmitter 110b, the secondary coil 122B is optimally aligned to the primary coil 112b of the transmitter 110b and this may be indicated for example by a green LED indicator 254B.

Reference is now made to Fig. 4C showing a power receiver 1200 provided with at least two secondary overlapping coils 1202a, 1202b according to another embodiment of the invention. Efficient inductive power transfer may occur when either one of the power receiver's secondary coils 1202 is aligned to any primary coil 112. It is noted that known multi-coiled power receivers such as the double coiled receiver described in United States Patent No. 6,803,744, to Sabo, need to be specifically and non-rotatably aligned such that the two secondary coils are both coupled to primary coils simultaneously. In contradistinction to the prior art, in the multi-coiled power receiver 1200 of the present embodiment of the invention, only one secondary coil 1202 may align with one primary coil 112 at a time. Alignment may thereby be achieved at any angle and the multi-coiled power receiver 1200 may be rotated through 360 degrees or more about the axis X of the primary coil 112.

Furthermore, in the multi-coiled power receiver 1200, the distance between the secondary coils 1202 may advantageously be selected to differ from the inter-coil spacing of the wireless power surface array 1100. The multi-coil power receiver 1200 may then be moved laterally over the wireless power surface array 1100 and the driving unit of the wireless power array 1100 may activate the primary coils located closest to the wireless multi-coil power receiver 1200. As the wireless multi-coil power receiver 1200 is moved laterally, the secondary coils 1202a, 1202b may both receive power from the primary coils in their vicinity.

The wireless power transferred to both the secondary coils 1202a, 1202b may be subject to diode summation to produce a total voltage output. Because the two secondary coils 1202a, 1202b are never both aligned simultaneously, the total output voltage is smoothed and power fluctuations normally associated with power transfer to moving power receivers may be prevented. This increases overall efficiency and

reduces the need for large variations in the power provided to the wireless power array 1100.

Wireless power transfer models have been simulated to measure the efficiency of power transfer to multiple secondary coils from a power surface with inter coil separation of 8.8 cm. With voltage applied only to the primary coil closest to a pair of secondary coils separated by 4.4 cm (half the surface inter-coil separation), the efficiency of total energy transferred to the pair of secondary coils does not fall below 80% as the pair of secondary coils undergoes lateral translation along the surface. This efficiency is further improved by increasing the number of secondary coils, for example in simulations of a triplet of secondary coils spaced at 2.9 cm from each other efficiencies of 90% were achieved.

In other embodiments of the invention where a multilayered power surface is provided, each layer of primary coil arrays is offset from the others, for example by half the surface inter-coil separation. A single coiled wireless power receiver may be placed upon the multilayered power surface and the driving unit of the power surface configured to activate only the primary coils within the multilayered power surface located closest to alignment with the secondary coil of the power receiver regardless of its layer. In this way, the voltage, efficiency and power transferred to the receiving coil are greatly stabilized.

Wireless power arrays 1100 may be incorporated within any flat surface 1300 where it is convenient to provide power. Such surfaces include walls, floor areas, ceilings, desktops, workbenches, kitchen work surfaces and counter tops, shelves, doors and door panels and the like.

For example, Fig. 5 shows an exemplary horizontally orientated wireless power array 1100 and a wireless power receiver 120a electrically coupled to a computer 140a by means of a connecting cable 121a. The wireless power receiver 120a is placed upon the power array 1100 and is inductively coupled to a wireless power transmitter 110 therewithin. Power supplied to the computer 140a may power the computer 140a directly and/or recharge a rechargeable power cell thereof. The arrangement of Fig. 5A with wireless power receivers 120a connected by cables 121a, typically reduces the length and number of wires and cables 121a necessary when connecting a computer 140a to a power source, and thus may be beneficial in conference rooms and the like, where such wires are obstructing, unsightly and

generally inconvenient. It is noted that the wireless power receiver 120a may alternatively be integral to the computer 140a, and the connecting cable 121a thereby dispensed with altogether.

Reference is now made to Fig. 6A, illustrating a wireless power coupling system 600A provided for transmitting power wirelessly to at least one electric load (not shown) via a wireless power receiver 6120A. The wireless power coupling system 600A is configured to have different coil sizes at a determined ratio, according to another embodiment of the invention.

The wireless power coupling system 600A comprises a wireless power receiver 6120A with at least one secondary coil 6122 of a first size. The secondary coil 6120 is configured to couple with a wireless power transmitter 6110 having a multi-coil array comprising primary coils 6112a, 6112b and 6112c (collectively 6112, shown as an example in which the number of coils is not limiting). The primary coils 6112 have a second size. The wireless power transmitter and the associated transmission array may be incorporated within any flat surface 6130 where it is convenient to provide wireless power. Such surfaces may include desktops, workbenches, walls, floor areas, ceilings, kitchen work surfaces and counter tops, shelves, doors and door panels and the like.

Efficient wireless power transfer may occur when the size of the secondary coil 6122 of the wireless is greater than the size of each ultra-thin primary coil 6112 such that dead spots, effecting efficient wireless power transfer, are eliminated. The ratio of the sizes of primary and secondary coils may be selected to provide efficient wireless transfer. Where appropriate the ratio of primary coil width  $D_T$  to secondary coil width  $D_R$  may be between  $2/3$  and  $1/4$ . Alternatively the ratio of primary coil width  $D_T$  to secondary coil width  $D_R$  may be above  $2/3$  or below  $1/4$  as required. Accordingly the reciprocal ratio of secondary coil width  $D_R$  to primary coil width  $D_T$  may be between 1.5 and 4. Alternatively, the ratio of secondary coil width  $D_R$  to primary coil width  $D_T$  may be below 1.5 and above 4, as required.

With such configuration, following these ratios a single secondary coil may encompass at least one primary coil wherever it is situated above the surface. Although in some embodiments overlapping secondary coils may be preferred, it is noted that the larger width of the secondary coil may eliminate the need for multiple secondary coils overlapping.

Where the coils are circular in shape, the widths of the primary coil and secondary coil may be their diameters. Where the coils are not circular the width of the coil may be the distance between the most extreme edges of the coil, for example, in a near elliptical coil, the width may be the major axis of the ellipse. Alternatively,  
5 the width of the coil may be the distance between the closes edges of the coil, for example, in a near elliptical coil, the width may be the minor axis of the ellipse.

Furthermore, the secondary coil may comprise non-circular shapes enabling a fit of a rectangular add-on at the bottom of a mobile device for example.

Reference is now made to Fig. 6B showing a wireless power coupling system  
10 600B provided for transmitting power wirelessly to at least one electric load (not shown) via a wireless power receiver 6120B comprising overlapping secondary coils, according to yet another embodiment of the invention. Efficient wireless power transfer between a multi-coiled power receiver and a multi-coiled power transmitter may occur when either one of the power receiver's secondary coils 6122a, 6122b and  
15 6122c associated with the multi-coiled power receiver is aligned to any ultra-thin primary coils 6122a, 6122b and 6122c associated with the multi-coiled power transmitter.

Furthermore, in the multi-coiled power receiver 6122a, 6122b and 6122c, the overlapping segment 6123 between the secondary coils 6122a, 6122b and 6122c may  
20 advantageously be selected to differ from the inter-coil spacing of the wireless power transmitter surface coil array 6110. The multi-coil power receiver 6120 may then be moved laterally over the wireless power surface array 6110 and the driving unit of the wireless power array 6110 may activate the ultra-thin primary coils located closest to the wireless multi-coil power receiver 6120. As the wireless multi-coil power receiver  
25 6120 is moved laterally, the secondary coils 6122a, 6122b and 6122c may receive power from the ultra-thin primary coils 112 in their vicinity. The wireless power transferred to all the secondary coils 6122a, 6122b and 6122c undergoes diode summation to produce a total voltage output. Because the three secondary coils 122 are never all aligned simultaneously, the total output voltage is smoothed and power  
30 fluctuations normally associated with power transfer to moving power receivers may be prevented. This increases overall efficiency and reduces the need for large variations in the power provided to the wireless power ultra-thin array 6110.

It is noted that for the presentation of three overlapping secondary coils 6122 are shown in a non-limiting manner. For practical reasons, only two overlapping coils may be necessary to reach efficient wireless power transfer.

5 In a wireless power receiver including multiple secondary coils, power may be drawn by an electric load from one secondary coil or from more than one secondary coil as required. Accordingly the multiple secondary coils may be connected to the electric load in various configurations.

10 In some embodiments, the multiple secondary coils may be passively connected directly, or via a rectifier, to the electric load so as to provide power thereto. Alternatively, the coils may be connected to the electric load via an active coil selector operable to select the secondary coil most suited to receive power wirelessly and to connect the selected coil to the load.

15 According to one passive configuration, the multiple secondary coils may be connected, possibly via a rectifier, in parallel each individually to the electric load such that any power received by any of the secondary coils is transferred to the electric load.

20 Alternatively the multiple secondary coils may be connected to one another in series to form a chain of secondary coils covering a larger area of a power transmitter. The chain of secondary coils could then be connected to the electric load such that power received by any of the secondary coils from the power transmitter is transferred to the electric load.

Reference is now made to the block diagrams of Figs. 6C and 6D schematically representing two possible passive configurations for wireless power receivers having multiple secondary coils.

25 With reference to Fig. 6C, a first configuration of a multiple coil wireless power receiver 600C is shown. The multiple coil wireless power receiver 600C includes an array of secondary coils 621C, 622C, 623C, a rectifier 626C and an electric load 628C, such as a chargeable battery or the like. The secondary coils 621C, 622C, 623C may each be connected individually to the rectifier 626C.

30 It is noted that in the first configuration of a multiple coil wireless power receiver 600C power received by any of the secondary coils 621C, 622C, 623C will be transferred to the load.

With reference now to Fig. 6D, a second configuration of a multiple coil wireless power receiver 600D is shown. The multiple coil wireless power receiver 600D includes an array of secondary coils 621D, 622D, 623D, a rectifier 626D and an electric load 628D, such as a chargeable battery or the like. The secondary coils 621D, 622D, 623D of the array are connected to each other in series to form an extended secondary coil. The extended secondary coil array is connected to the rectifier 626D such that if a primary coil of a wireless transmitter is activated in the vicinity of any of the secondary coils, the array will receive power and transfer the received power to the electric load.

It is particularly noted that in the second configuration, where appropriate, an extended secondary coil may be produced by spreading the turns of a single secondary coil over a larger area.

Referring now to Fig. 6E a third configuration of a multiple coil wireless power receiver 600E, is schematically represented. The third configuration of a multiple coil wireless power receiver 600E includes an array of secondary coils 621E, 622E, 623E, a receiver coil selector 624E, a rectifier 626E and an electric load 628E, such as a chargeable battery or the like. The secondary coils 621E, 622E, 623E of the array are each connected to receiver coil selector 624E.

The receiver coil selector 624E may be operable to select one of the secondary coils 621E, 622E, 623E and to connect the selected coil to the load. Accordingly algorithms may be used to select the coil based upon feedback parameters communicated to the selector. For example, when the wireless power receiver 600E is brought into the vicinity of a wireless power transmitter the selector 624E may calculate the coupling factor for each of the secondary coils 621E, 622E, 623E and select the coil with highest coupling factor  $k$ , where  $k$  is given by the equation:

$$k = (1/2\pi f) \sqrt{(Z_{\text{Ref}} Z_S / L_P L_S)}$$

where  $f$  is the transmission frequency,  $L_P$  is the primary inductance and  $L_S$  is the secondary inductance,  $Z_{\text{Ref}}$  is the reflected impedance of the receiver circuit as measured in the transmitter circuit, and  $Z_S$  is the secondary impedance given by

$$Z_S = 1/j2\pi f C_S + j2\pi f L_S + R_S + R_{\text{Load}}$$

where  $C_S$  is the capacitance of the receiver circuit,  $R_S$  is the resistance of the receiver circuit and  $R_{\text{Load}}$  is the resistance of the electric load.

Accordingly, the coupling factor may be calculated by obtaining a number of parameters such as transmission frequency of the driving voltage, inductance of the primary coil circuit, inductance of the secondary coil circuit, the capacitance of the primary coil circuit, the capacitance of the secondary coil circuit, the resistance of the primary coil circuit, the resistance of the secondary coil circuit, the resistance of the load and the like.

Reference is now made to Fig. 8A, illustrating a possible rectangular overlapping secondary coil arrangement 722 for an electric mobile device on a multi-coil surface. The overlapping secondary coil arrangement 722 may be provided as a add-on retrofittable to an electrical device 720 and may have a substantially rectangular shape as of the host electrical device 720. The overlapping secondary coil arrangement 722 may have a first layer comprising two secondary coils 732 and 732' and a second layer comprising a third secondary coil 734 partially overlapping the two secondary coils 732 and 732' of the first layer. The secondary coils 732 and 732' of the first layer may be spaced apart at a distance selected according to the inter-spacing of the multiple coils of the transmitting surface 710.

It is noted that appropriate inter-spacing design of the wireless transmitting surface and the spacing of the secondary coils may help to achieve power transfer efficiency and reduce the necessity of coil alignment.

Accordingly, Fig. 7B shows the cross-section A-A as indicated in Fig. 7A, where the primary coils 712, 714, 716 represent only a partial set of the multiple coil surface.

With regard to the multi-coil surface, it is noted that the surface may be architecturally designed in various configurations as illustrated schematically in Figs. 8A-C. It is noted that the drivers may be operable via a controller (not shown).

Fig. 8A illustrates a transmitting multi-coil surface configuration of a subset in which the primary coils are driven by a common driver associated with the multi-coil surface; Fig. 8B illustrates a transmitting multi-coil surface configuration in which a subset of primary coils are driven by a common driver associated with the multi-coil surface; and Fig. 8C illustrates a transmitting multi-coil surface configuration in which each cluster comprising a set of primary coils of the surface, where each cluster is driving a dedicated common driver for each cluster.

Reference is now made to Fig. 9A, illustrating a signal transfer system 2101 according to yet another embodiment of the invention. The signal transfer system 2101 is used for locating a secondary coil  $L_{22}$  wired to an electric load 2281, which is placed somewhere over a multi-coil power transmission surface 2211.

5       The multi-coil power transmission surface 2211 comprises an array of primary coils  $L_{1n}$  each connected to a driver 2231 wired to a power source 2241. The signal transfer system 2101 includes a transmission circuit 2141 wired to the secondary coil 2221 and a reception circuit 2161 connected to the driver 2231. The transmission circuit 2141 includes a half-wave rectifier 2144 connected to an ancillary load 2142  
10   and the reception circuit 2161 is configured to detect second harmonic signals in the power supplied to the primary inductive coil  $L_{1n}$  when the secondary inductive coil  $L_{22}$  is coupled thereto.

      The driver 2231 is configured to selectively operate each primary inductive coil  $L_{1n}$  in turn preferably at low power so as to identify which primary inductive coil  
15   is closest to the secondary inductive coil  $L_{22}$ . When a secondary coil  $L_{22}$  is detected, the driver 2231 is then configured to operate the primary inductive coil  $L_{1n}$  closest to the secondary inductive coil  $L_{22}$  at a high power. It will be appreciated that for some purposes it may be desirable to disconnect the transmission circuit 2141 after the secondary inductive coil  $L_{22}$  is coupled to a primary coil  $L_{1n}$ .

20       Thus a number of related technologies are presented that use signal transfer systems across an inductive power coupling to regulate the power and to detect and align the two coils.

      Reference is now made to Fig. 9B, illustrating a possible signal transfer system 1700A according to yet another embodiment of the invention. The signal  
25   transfer system 1700A is used for locating a power receiver having a secondary coil  $L_{22}$  wired to an electric load 1781, which is placed somewhere over a multi-outlet power transmission surface 1711, enabling selection of a wireless power outlet of the multi-outlet power transmission surface closest to the location of the power receiver.

      It is noted that when referring to the closest location, it is not necessarily  
30   represented by the shortest physical distance, rather may be referring to the closest effective location based upon signal communication analysis.

      The multi-outlet power transmission surface 1711 comprises an array of wireless power outlets, each having a primary coil indicated by  $L_{11}$ ,  $L_{12}$ , and  $L_{13}$

through to  $L_{1n}$  where each primary coil is connected to a driver 1731 wired to a power source (not shown) and to a reception circuit of a signal receiver 1761. The signal transfer system 1700A includes a transmission circuit 1741 wired to the secondary coil  $L_{22}$  of a power receiver where the transmission circuit 1741 includes a signal  
 5 transmitter 1742 operable to transmit detection signals ( $DET_s$ ).

Each signal receiver 1761 of the primary inductive coil  $L_{1n}$ , is configured to forward a detection signal ( $DET_s$ ) received from the signal transmitter unit 1742 to the outlet selector unit 1766, optionally through a signal filter 1762, filtering the detected communication signals for known communication signal frequencies. The  
 10 filtered detected signals may be forwarded for signal-to-noise ratio (SNR) analysis by the signal processing unit 1763. The signal processing unit 1763 may serve various analysis requirements, such as to identify which primary inductive coil  $L_{1n}$  is closest effectively to the secondary inductive coil  $L_{22}$ . When a secondary coil  $L_{22}$  is detected, the signal controller 1764 drives the driver 1731 to operate the primary inductive coil  
 15  $L_{1n}$  closest to the secondary inductive coil  $L_{22}$  at a high power.

Accordingly, the current architecture of the signal transfer system 1700A, each primary inductive coil  $L_{1n}$  may have a sensing mechanism and may use a signal receiver 1761 without a limiting multiplexer, as may be the case when prior art architectures are considered. Further, the sensing mechanism and the activation of the  
 20 closest wireless power outlet may be operable to transmit a control signal, triggered by the processing unit 1763 as a result of the signal-quality computation. The driver 1731 is configured to selectively operate each primary inductive coil  $L_{1n}$ , in turn, upon receiving a control signal identified as the primary inductive coil which is closest effectively to the secondary inductive coil  $L_{22}$ . Further, when a secondary coil  $L_{22}$  is  
 25 detected, the driver 1731 may be configured to operate the primary inductive coil  $L_{1n}$  closest effectively to the secondary inductive coil  $L_{22}$  at a high power.

The signal transfer system architecture, for example, based upon SNR analysis or the like, as described hereinabove, may have various possible applications and commercial uses, such as:

- 30 • Power Transmission Surfaces may allow a wide active range for different shapes of receiver sizes.
- In-vehicle power transmission surfaces may provide power transfer in transit, to receiver units which may be prone to movements while in motion.

It is noted that the architecture of the signal transfer system coupled with SNR based analysis may require only fine-tuning the SNR thresholds per specific product, avoiding the need for knowing coil specific parameters, coil specific structure, coil-array topology and/or coil-array overlapping, or defining a coil-array specific configuration. . Accordingly, power related computations may not be required.

It is further noted that the processing unit 1763 of the signal transfer system 1700A is further operable to perform other digital signal analysis methods in addition to or alongside signal-to-noise-ratio.

### **Power Regulation**

Efficient power transfer requires regulation. In order to regulate the characteristics of the power provided to the secondary coil 122, such as voltage, current, temperature and the like, feedback from the device to the power transmitter 110 is desirable. According to further embodiments of the present invention, a power regulator 300 provides a communications channel between the power receiver 120 wired to the load and the power transmitter 110.

In inductive couples, the communication channel may be used to transfer data between the primary and the secondary coils. The data transferred may be used to regulate the power transfer, for example. Typically the signal carries encoded data pertaining to one or more items of the list below:

- the presence of the electric load;
- the required operating voltage for the electric load;
- the required operating current for the electric load;
- the required operating temperature for the electric load;
- the measured operating voltage for the electric load;
- the measured operating current for the electric load;
- the measured operating temperature for the electric load, or
- a user identification code.

Such a signal may be useful in various inductive energy couples usable with the present invention such as transformers, DC-to-DC converters, AC-to-DC

converters, AC-to-AC converters, flyback transformers, flyback converters, full-bridge converters, half-bridge converters and forward converters.

Technical and scientific terms used herein should have the same meaning as commonly understood by one of ordinary skill in the art to which the disclosure  
5 pertains. Nevertheless, it is expected that during the life of a patent maturing from this application many relevant systems and methods will be developed. Accordingly, the scope of the terms such as computing unit, network, display, memory, server and the like are intended to include all such new technologies a priori.

As used herein the term “about” refers to at least  $\pm 10\%$ .

10 The terms "comprises", "comprising", "includes", "including", “having” and their conjugates mean "including but not limited to" and indicate that the components listed are included, but not generally to the exclusion of other components. Such terms encompass the terms "consisting of" and "consisting essentially of".

The phrase "consisting essentially of" means that the composition or method  
15 may include additional ingredients and/or steps, but only if the additional ingredients and/or steps do not materially alter the basic and novel characteristics of the claimed composition or method.

As used herein, the singular form "a", "an" and "the" may include plural references unless the context clearly dictates otherwise. For example, the term "a  
20 compound" or "at least one compound" may include a plurality of compounds, including mixtures thereof.

The word “exemplary” is used herein to mean “serving as an example, instance or illustration”. Any embodiment described as “exemplary” is not necessarily to be construed as preferred or advantageous over other embodiments or to exclude  
25 the incorporation of features from other embodiments.

The word “optionally” is used herein to mean “is provided in some embodiments and not provided in other embodiments”. Any particular embodiment of the disclosure may include a plurality of “optional” features unless such features conflict.

30 Whenever a numerical range is indicated herein, it is meant to include any cited numeral (fractional or integral) within the indicated range. The phrases “ranging/ranges between” a first indicate number and a second indicate number and “ranging/ranges from” a first indicate number “to” a second indicate number are used herein interchangeably and are meant to include the first and second indicated

numbers and all the fractional and integral numerals therebetween. It should be understood, therefore, that the description in range format is merely for convenience and brevity and should not be construed as an inflexible limitation on the scope of the disclosure. Accordingly, the description of a range should be considered to have specifically disclosed all the possible sub-ranges as well as individual numerical values within that range. For example, description of a range such as from 1 to 6 should be considered to have specifically disclosed sub-ranges such as from 1 to 3, from 1 to 4, from 1 to 5, from 2 to 4, from 2 to 6, from 3 to 6 etc., as well as individual numbers within that range, for example, 1, 2, 3, 4, 5, and 6 as well as non-integral intermediate values. This applies regardless of the breadth of the range.

It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the disclosure, which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable sub-combination or as suitable in any other described embodiment of the disclosure. Certain features described in the context of various embodiments are not to be considered essential features of those embodiments, unless the embodiment is inoperative without those elements.

Although the invention has been described in conjunction with specific embodiments thereof, it is evident that other alternatives, modifications, variations and equivalents will be apparent to those skilled in the art. Accordingly, it is intended to embrace all such alternatives, modifications, variations and equivalents that fall within the spirit of the invention and the broad scope of the appended claims.

Additionally, the various embodiments set forth hereinabove are described in terms of exemplary block diagrams, flow charts and other illustrations. As will be apparent to those of ordinary skill in the art, the illustrated embodiments and their various alternatives may be implemented without confinement to the illustrated examples. For example, a block diagram and the accompanying description should not be construed as mandating a particular architecture, layout or configuration.

The presence of broadening words and phrases such as “one or more,” “at least,” “but not limited to” or other like phrases in some instances shall not be read to mean that the narrower case is intended or required in instances where such broadening phrases may be absent. The use of the term “module” does not imply that the components or functionality described or claimed as part of the module are all

configured in a common package. Indeed, any or all of the various components of a module, whether control logic or other components, can be combined in a single package or separately maintained and can further be distributed in multiple groupings or packages or across multiple locations.

5           Furthermore, embodiments may be implemented by hardware, software, firmware, middleware, microcode, hardware description languages, or any combination thereof. When implemented in software, firmware, middleware or microcode, the program code or code segments to perform the necessary tasks may be stored in a computer-readable medium such as a storage medium. Processors may  
10   perform the necessary tasks.

          All publications, patents and patent applications mentioned in this specification are herein incorporated in their entirety by reference into the specification, to the same extent as if each individual publication, patent or patent application was specifically and individually indicated to be incorporated herein by  
15   reference. In addition, citation or identification of any reference in this application shall not be construed as an admission that such reference is available as prior art to the present disclosure. To the extent that section headings are used, they should not be construed as necessarily limiting.

          The scope of the disclosed subject matter is defined by the appended claims  
20   and includes both combinations and sub combinations of the various features described hereinabove as well as variations and modifications thereof, which would occur to persons skilled in the art upon reading the foregoing description.

          In the claims, the word “comprise”, and variations thereof such as “comprises”, “comprising” and the like indicate that the components listed are  
25   included, but not generally to the exclusion of other components.

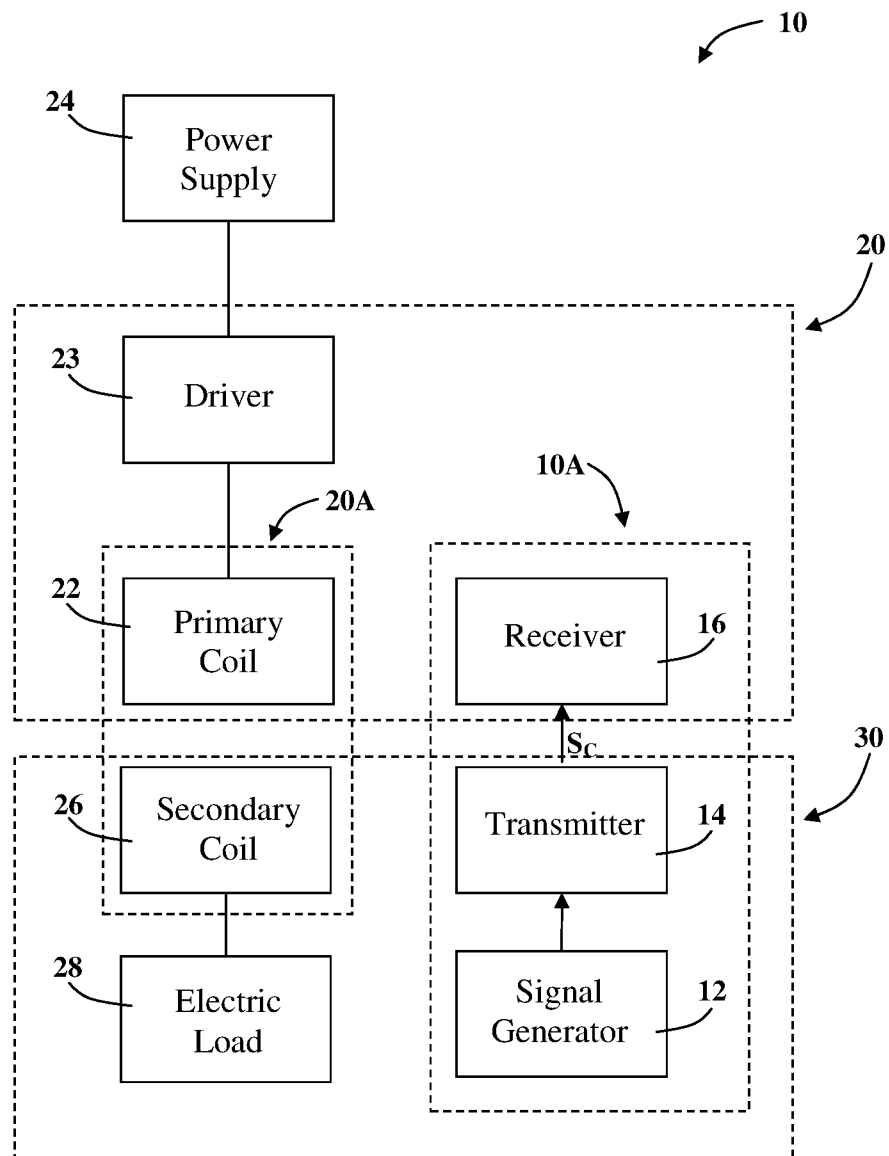
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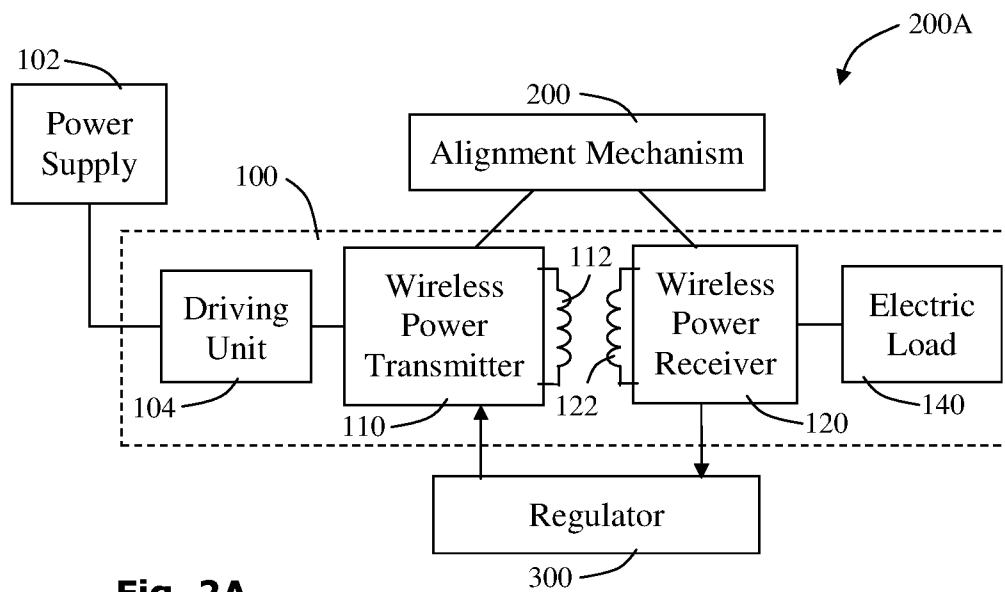
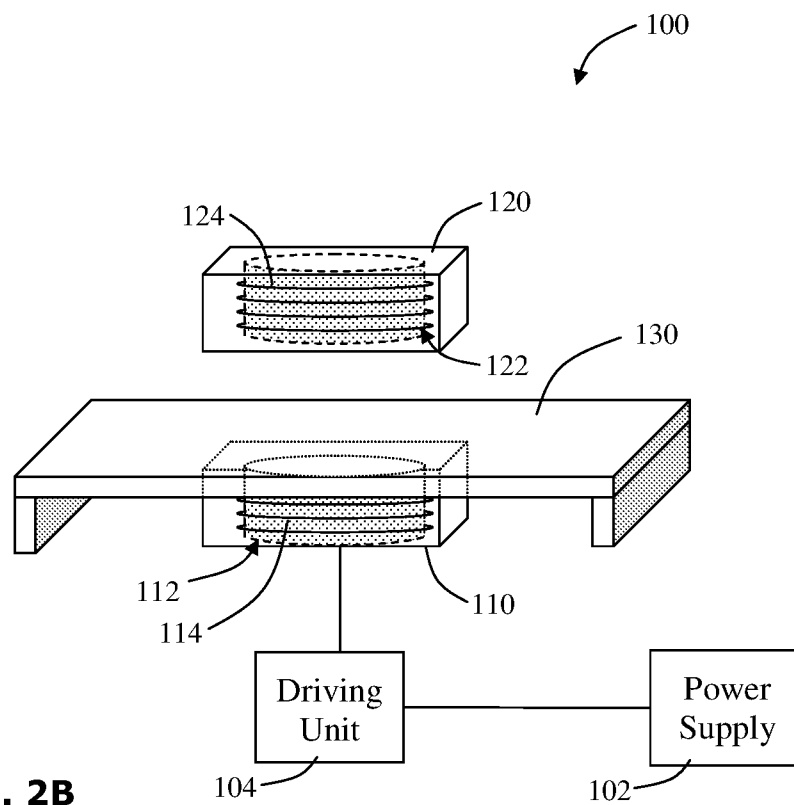
## CLAIMS

1. A wireless power transmitter for transferring power wirelessly to at least one electric load via a wireless power receiver, said wireless power transmitter  
5 comprising:  
  
a multi-coil power transmission surface comprising an array of primary coils for wirelessly coupling with at least one secondary coil of said wireless power receiver located in front of said multi-coil power transmission surface,  
  
wherein said array of primary coils comprises primary coils having  
10 diameters selected to be smaller than the diameter of said secondary coil such that when a secondary coil is placed over the multi-coil power transmission surface at least one primary coil is situated substantially within the compass of the secondary coil.
2. The wireless power transmitter of claim 1, further comprising a driver wired to a  
15 power source and operable to drive each primary coil of said array.
3. The wireless power transmitter of claim 1, wherein each primary coil of said array of primary coils is independently connected to the power source via said at least one driver.
4. The wireless power transmitter of claim 1, comprising a plurality of drivers, each  
20 driver being wired to a power source and operable to drive a cluster of primary coils.
5. The wireless power transmitter of claim 1, wherein said diameter of said primary coil is selected such that the ratio between the diameter of the secondary coil and the diameter of the primary coils is above three halves.
- 25 6. The wireless power transmitter of claim 1, wherein said diameter of said primary coil is selected such that the ratio between the diameter of the secondary coil and the diameter of the primary coils is above four.
7. The wireless power transmitter of claim 1, wherein said diameter of said primary coil is selected such that the ratio between the diameter of the secondary coil and  
30 the diameter of the primary coils is above three halves and below four.

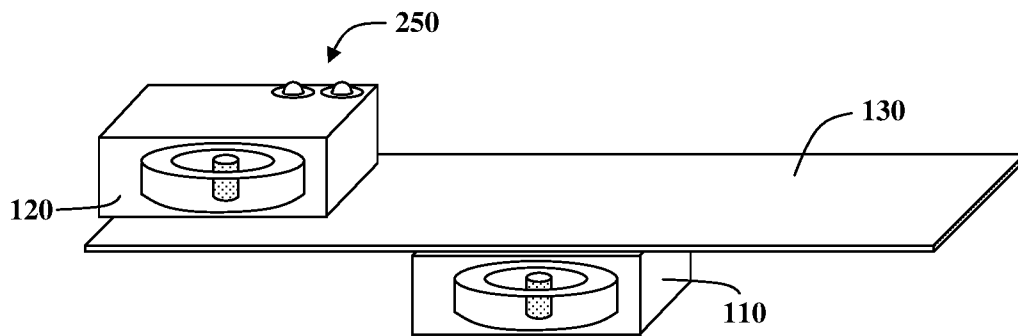
8. The wireless power transmitter of claim 1, wherein each primary coil of said array of primary coils is spaced in said multi-coil power transmission surface at an inter-coil spacing distance and said inter-coil spacing distance is zero.
9. The wireless power transmitter of claim 1, wherein each primary coil of said array of primary coils is spaced in said multi-coil power transmission surface at an inter-coil spacing distance and said inter-coil spacing distance is less than half of said secondary coil size.
10. The wireless power transmitter of claim 1, wherein each said primary coil is vertically offset from said secondary coil by a distance less than 14 millimeters.
- 10 11. The wireless power coupling system of claim 1, wherein said array of primary coils are shielded by an insulating layer.
12. The wireless power transmitter of claim 11, wherein said insulating layer is constructed from a material selected from at least one member of the group consisting of: glass, plastic mica, formica, wood, wood veneer, canvas, cardboard, stone, linoleum, paper and combinations thereof.
- 15 13. The wireless power transmitter of claim 1, wherein said secondary coil is not circular and said primary coils have diameters selected to be smaller than the major axis of said secondary coil.
14. The wireless power transmitter of claim 1, wherein said secondary coil is not circular and said primary coils have diameters selected to be no larger than two thirds of the major axis of said secondary coil.
- 20 15. A wireless power receiver for receiving power wirelessly from a wireless power transmitter, said wireless power receiver comprising:
  - at least a first secondary coil and a second secondary coil, each said secondary coil for wirelessly coupling with at least one primary coil of said wireless power transmitter;
  - wherein said first secondary coil overlaps said second secondary coil.
16. The wireless power receiver of claim 15, wherein said first secondary coil and said second secondary coil are offset by a distance which is less than half of the diameter of each of said secondary coil.
- 30

17. The wireless power receiver of claim 15, wherein said wireless power transmitter comprises an array of primary coils and said first secondary coil and said second secondary coil are offset by a distance which is at least half the inter-coil spacing of primary coils within said array.
- 5 18. The wireless power receiver of claim 15, wherein at least one of said first secondary coil and said second secondary coil is configured to align with at least one primary coil at any angle such that said wireless power receiver is rotatable through 360 degrees.
19. The wireless power receiver of claim 15, further comprising a power cord for  
10 connecting to at least one electric load.
20. The wireless power receiver of claim 15 further comprising a receiver coil selector operable to select one of at least said first secondary coil and said second secondary coil to connect to an electric load.
21. The wireless power receiver of claim 15 wherein said first secondary coil and  
15 said second secondary coil are connected in parallel to an electric load.

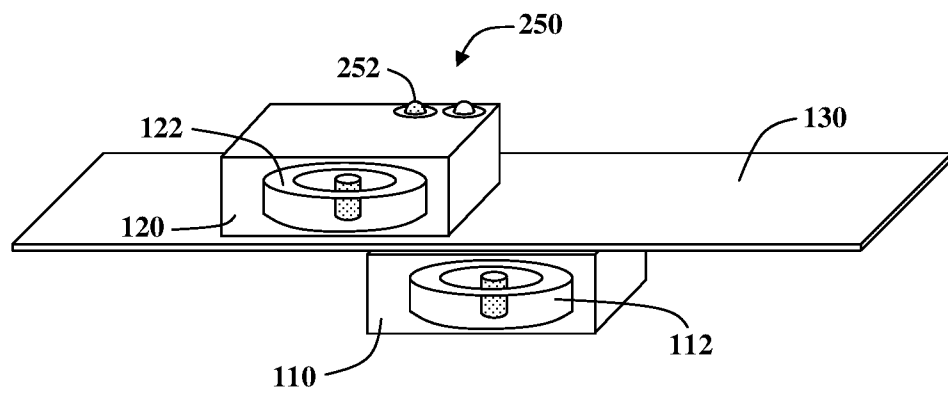
**1 / 11****Fig. 1**

**2 / 11****Fig. 2A****Fig. 2B**

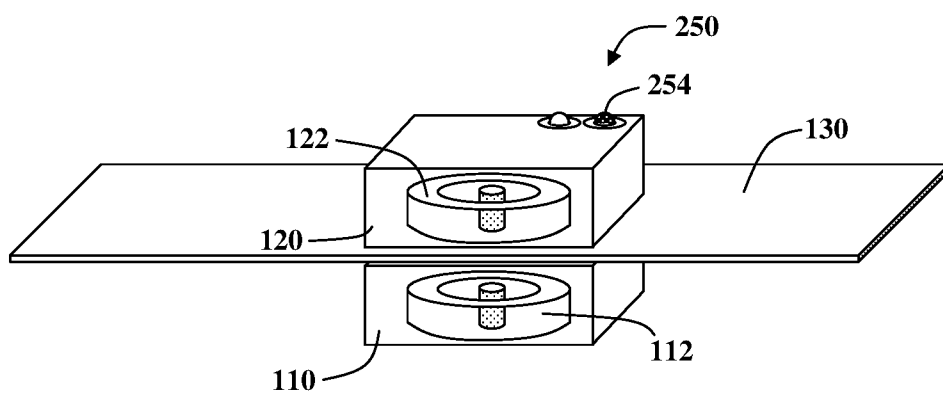
**3 / 11**



**Fig. 3A**



**Fig. 3B**



**Fig. 3C**

4 / 11

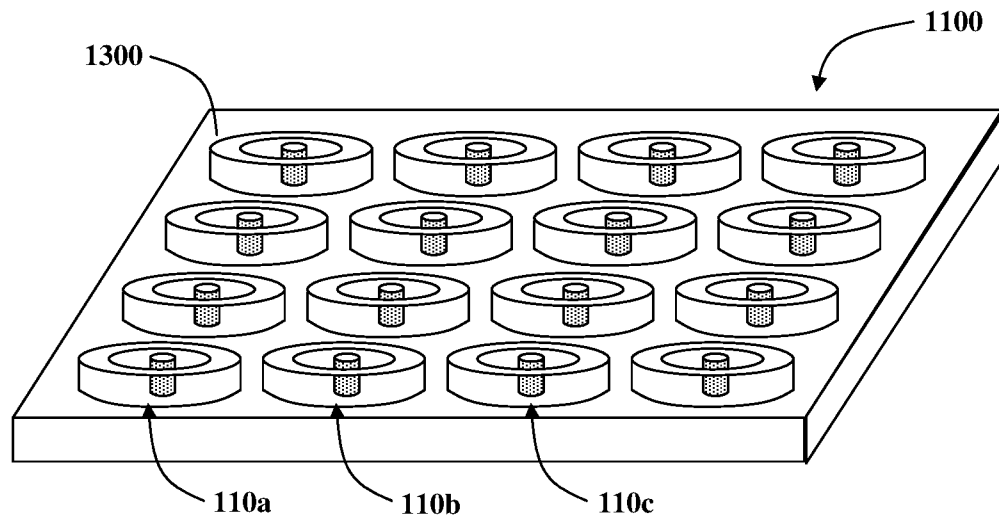


Fig. 4A

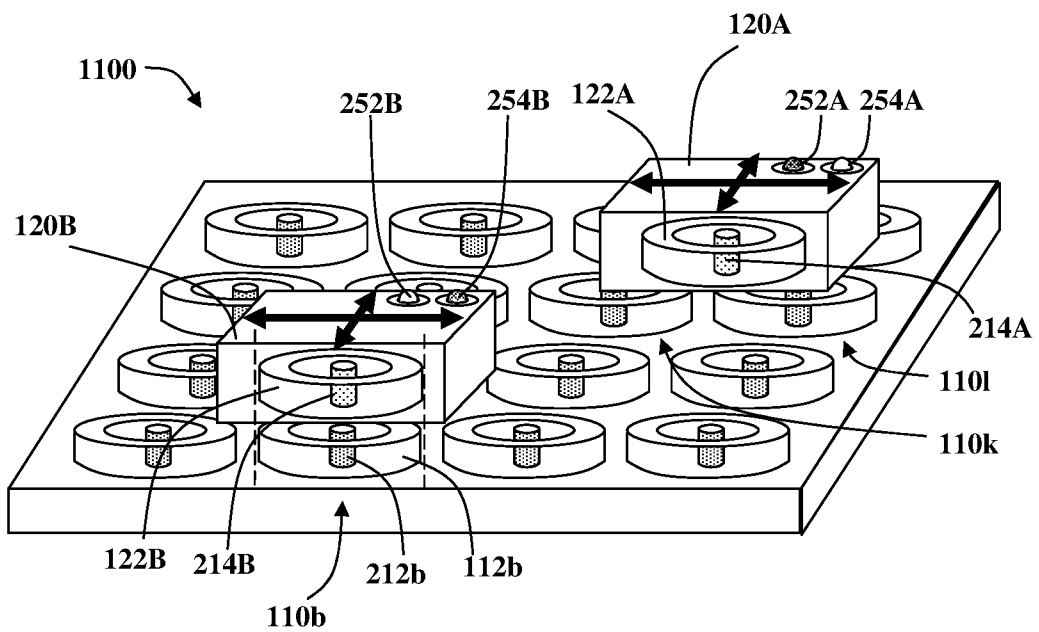
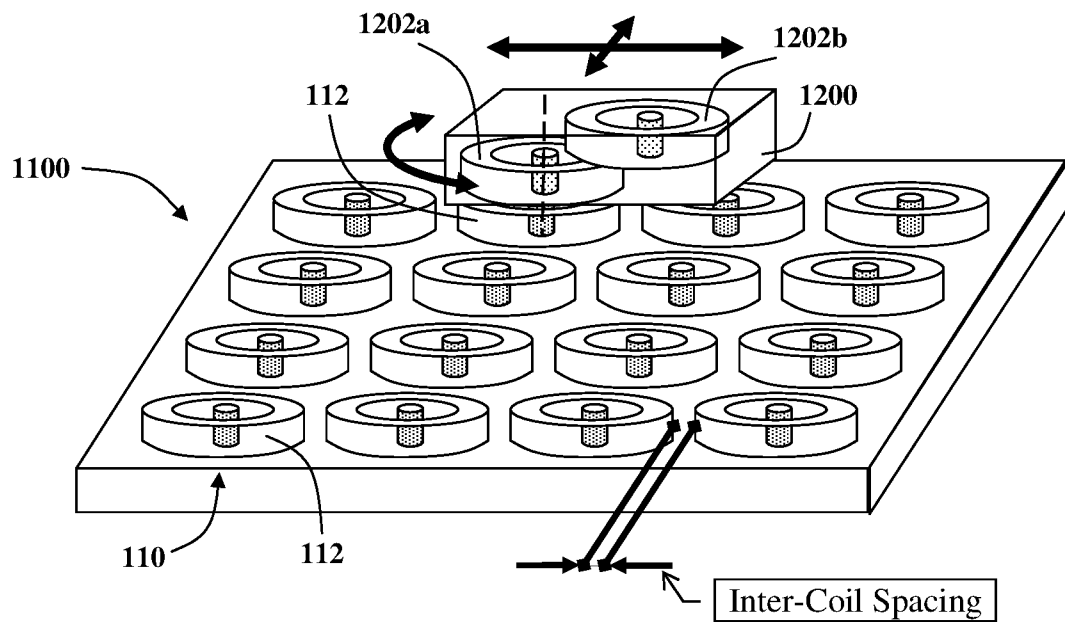
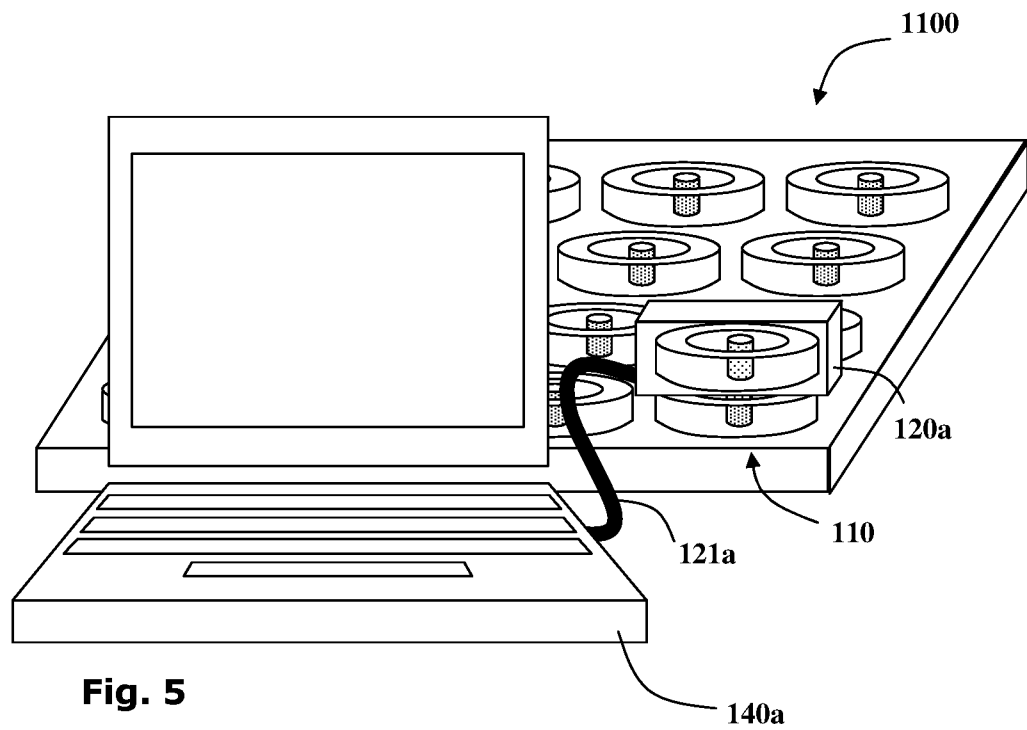


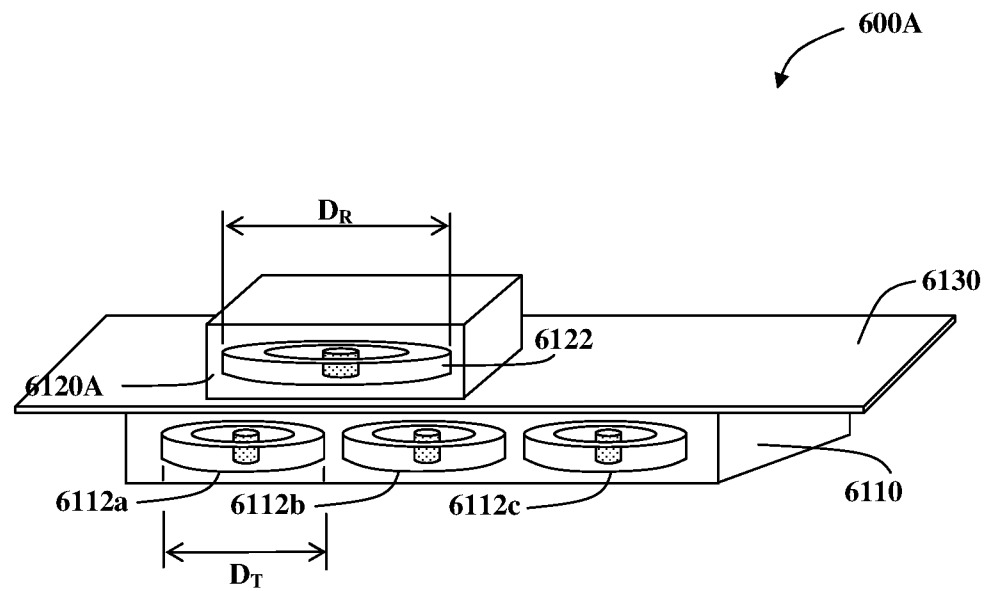
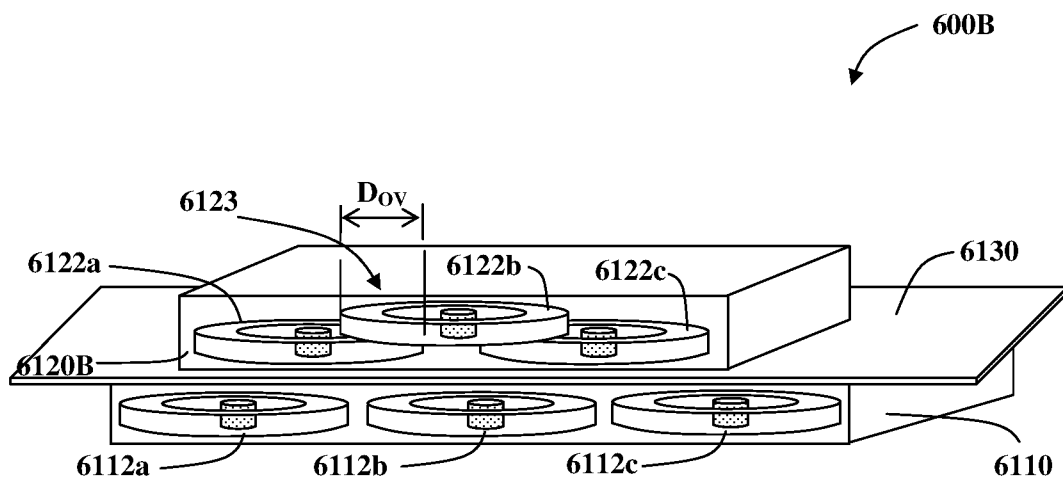
Fig. 4B



**Fig. 4C**



**Fig. 5**

**6 / 11****Fig. 6A****Fig. 6B**

7 / 11

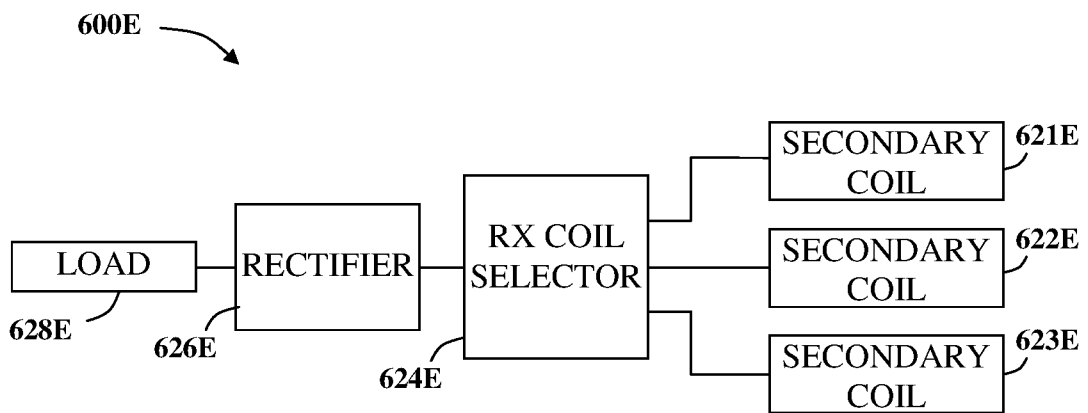
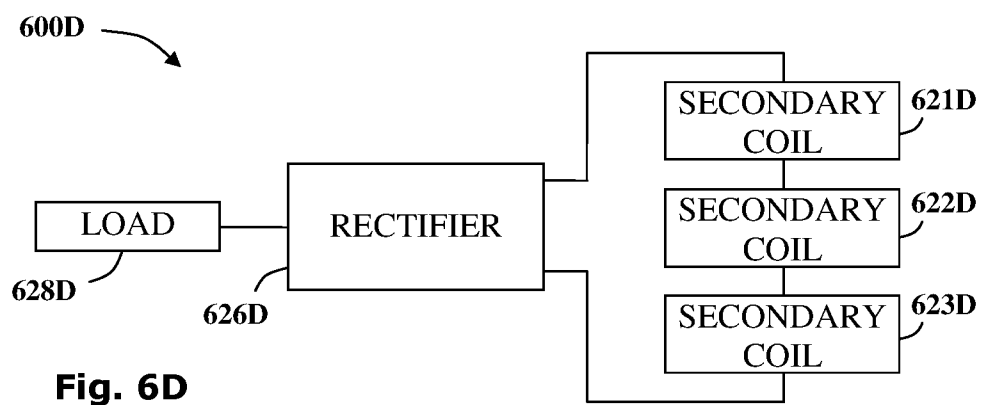
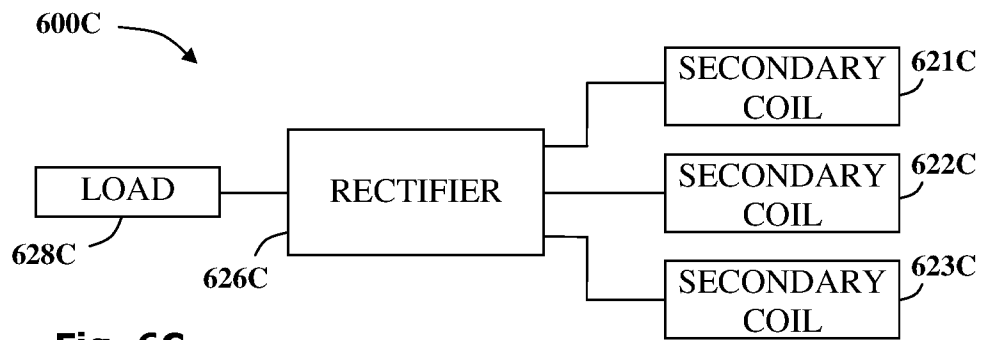
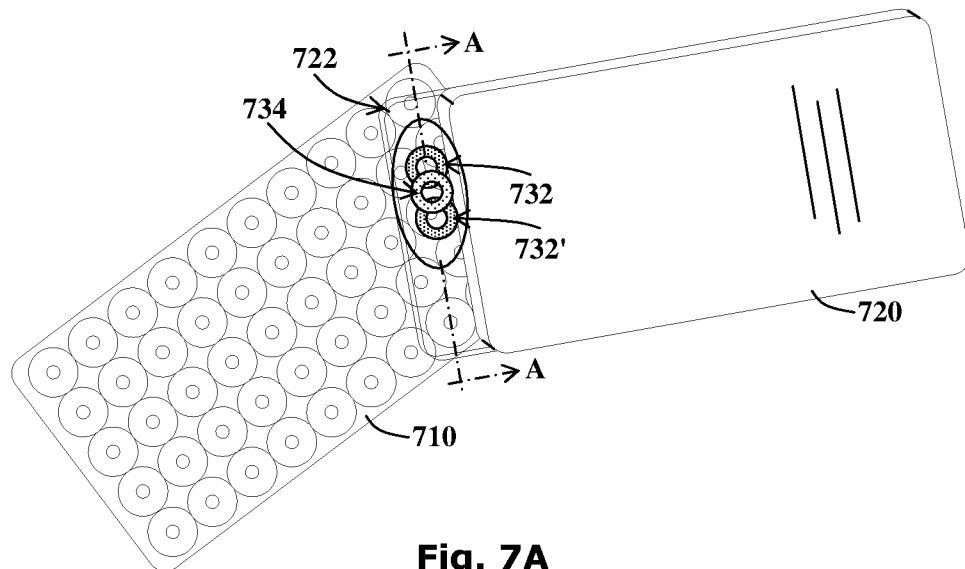
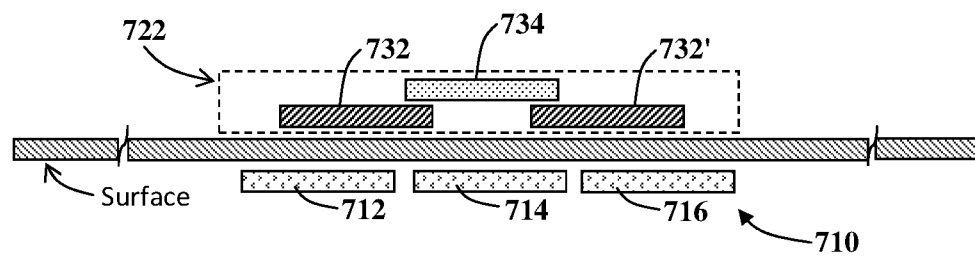
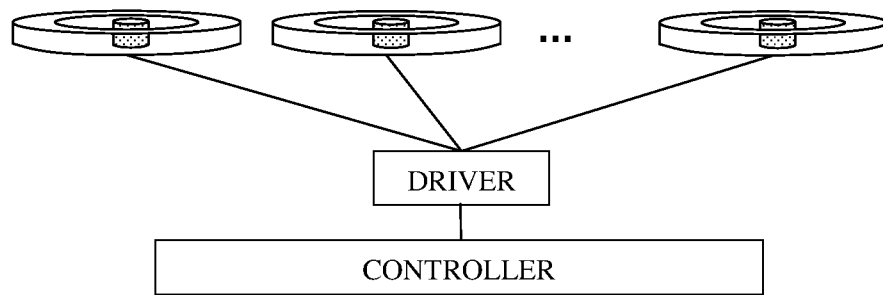
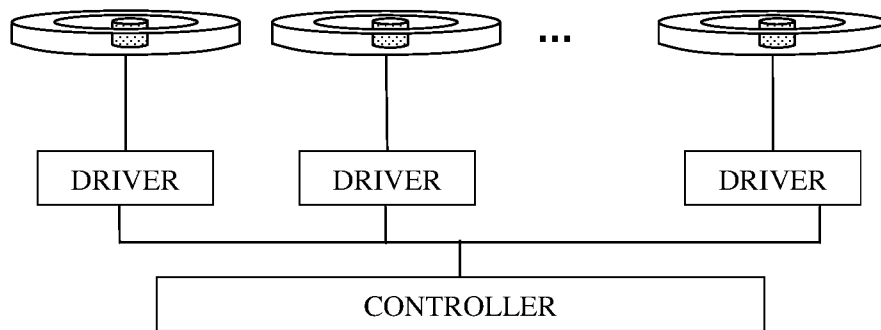
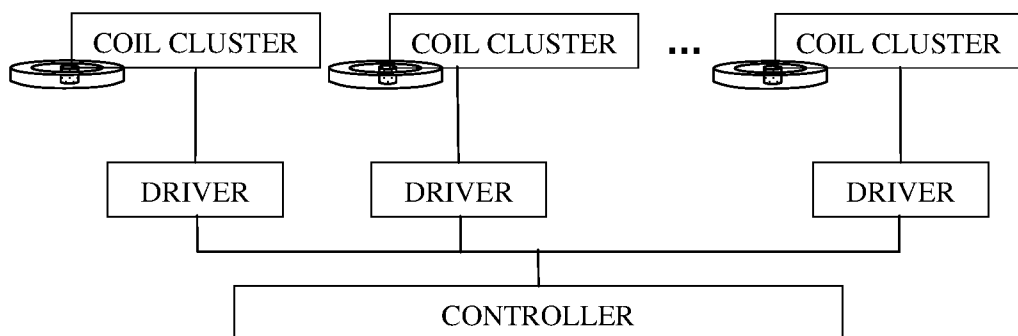


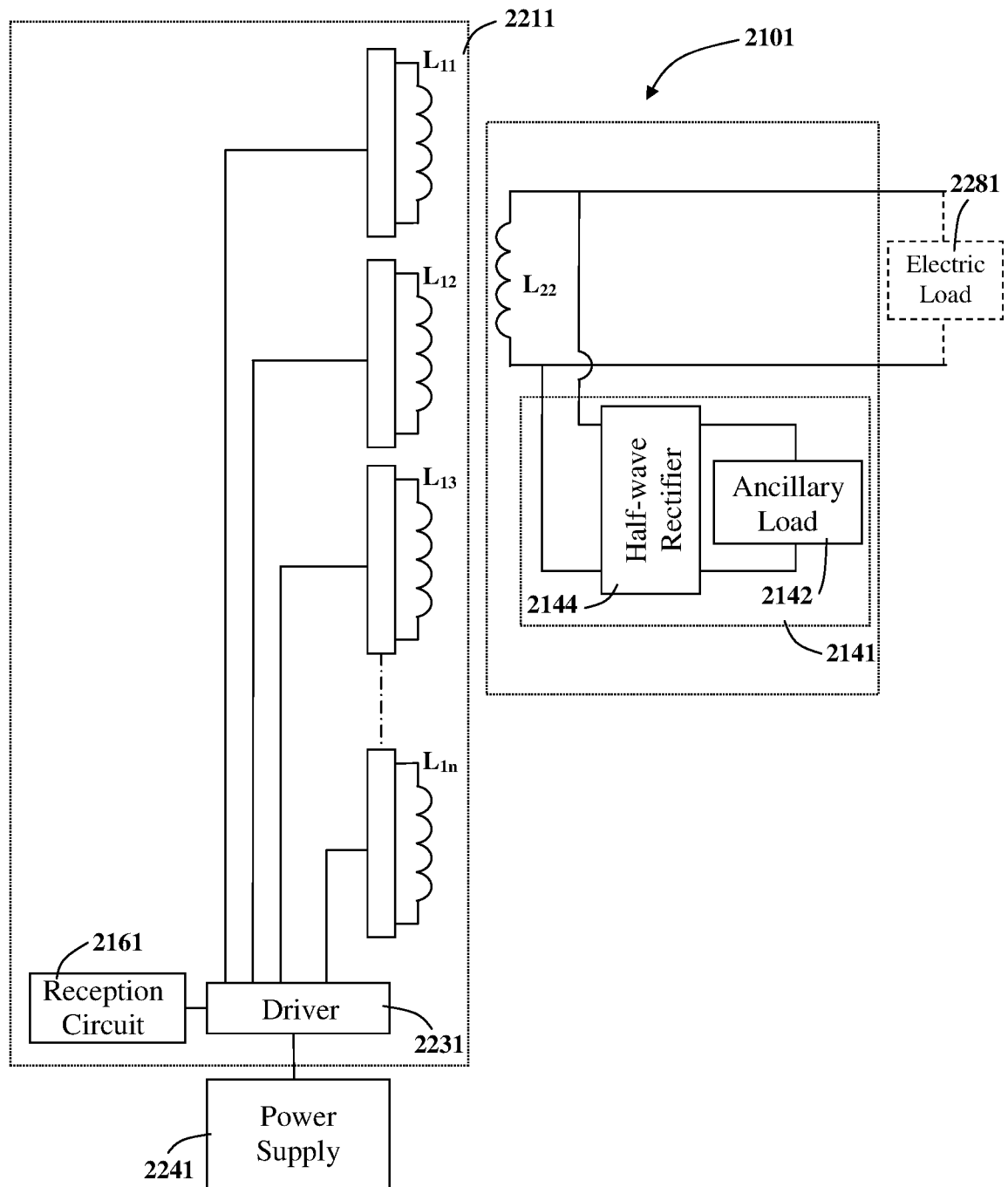
Fig. 6E

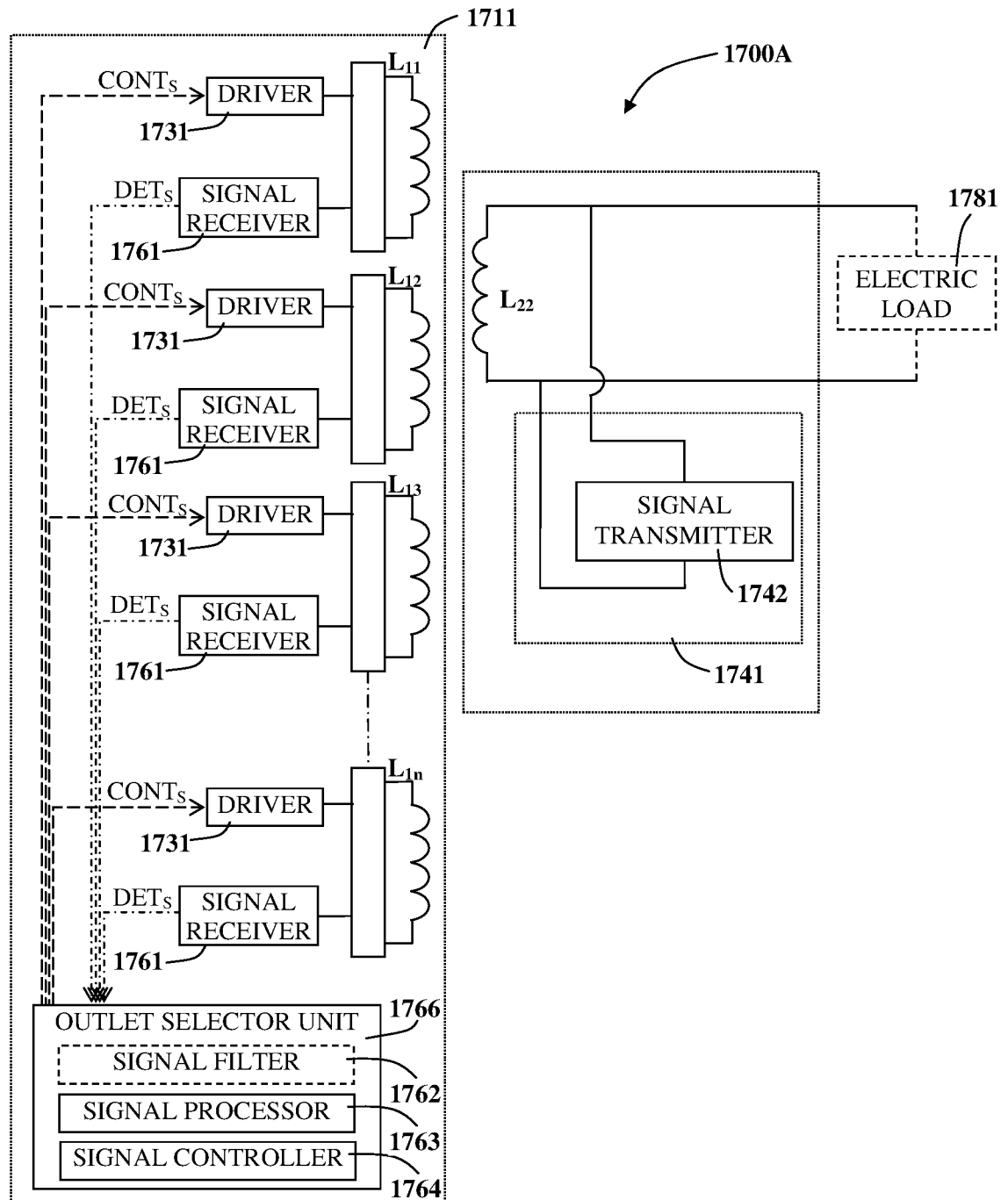
**8 / 11****Fig. 7A**

Section A-A

**Fig. 7B**

**9 / 11****Fig. 8A****Fig. 8B****Fig. 8C**

**10 / 11****Fig. 9A**

**11 / 11****Fig. 9B**

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/IL2015/050713

| <b>A. CLASSIFICATION OF SUBJECT MATTER</b><br>IPC (2015.01) H02J 5/00, H02J 7/02<br><br>According to International Patent Classification (IPC) or to both national classification and IPC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                             |                                                                       |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------|
| <b>B. FIELDS SEARCHED</b><br><br>Minimum documentation searched (classification system followed by classification symbols)<br>IPC (2015.01) H02J 5/00, H02J 7/02, H02J 17/00<br><br>Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched<br><br>Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)<br>Databases consulted: THOMSON INNOVATION, Esp@cenet, Google Patents, Google Scholar, FamPat database<br>Search terms used: wireless power, Inductive/primary - coil/wire/winding, diameter, radius, overlap, array                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                             |                                                                       |
| <b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                             |                                                                       |
| Category*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                          | Relevant to claim No.                                                 |
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| X                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | US 2006202665 A1 MICROSOFT CORP [US]<br>14 Sep 2006 (2006/09/14)<br>Fig 6   ¶ [0027]                                                                                                                                                                        | 1                                                                     |
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| <input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                             |                                                                       |
| * Special categories of cited documents:<br>"A" document defining the general state of the art which is not considered to be of particular relevance<br>"E" earlier application or patent but published on or after the international filing date<br>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)<br>"O" document referring to an oral disclosure, use, exhibition or other means<br>"P" document published prior to the international filing date but later than the priority date claimed<br>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention<br>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone<br>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art<br>"&" document member of the same patent family |                                                                                                                                                                                                                                                             |                                                                       |
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| Name and mailing address of the ISA:<br>Israel Patent Office<br>Technology Park, Bldg.5, Malcha, Jerusalem, 9695101, Israel<br>Facsimile No. 972-2-5651616                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                             | Authorized officer<br>COHAY Mattan<br><br>Telephone No. 972-2-5651611 |

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| C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |                                                                                                                                                                              |                       |
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| A                                                     | EP 2256895 A1 KONINKL PHILIPS ELECTRONICS NV [NL]; PHILIPS INTELLECTUAL PROPERTY [DE]<br>01 Dec 2010 (2010/12/01)<br>Figs 1-6                                                | 1-14                  |
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**Box No. III** Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See extra sheet.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☒ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

**Remark on Protest**

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/IL2015/050713

## **Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet):**

\* This International Searching Authority found multiple inventions in this international application, as follows:

|               |                                                                                              |               |
|---------------|----------------------------------------------------------------------------------------------|---------------|
| Invention/s 1 | An array of primary coils, each has a diameter smaller than the diameter of a secondary coil | Claim/s 1-14  |
| Invention/s 2 | A secondary coil comprising two overlaps coils.                                              | Claim/s 15-21 |

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