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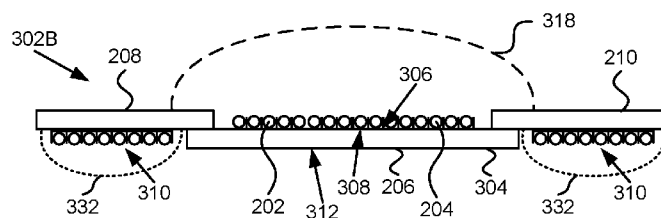
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(54) Title: BI-PLANE WIRELESS POWER TRANSMISSION PAD

**FIG. 3F**

(57) **Abstract:** An apparatus includes a first charging coil (202) with conductors arranged in a first winding pattern, a second charging coil (204) with conductors arranged in a second winding pattern, and a ferrite structure with a main section 206 with a top side, a first side section (208) and a second side section (210). A portion of the top side of the main section (206) is adjacent to a portion of the bottom side of the first side section (208) and the second side section 210. A portion of the first and second charging coils, (202), (204) are positioned adjacent to the top side of the main section (206). A portion of the first charging coil (202) is adjacent to the bottom of the first side section (208). A portion of the second charging coil (204) is adjacent to the bottom of the second side section (210).



BI-PLANE WIRELESS POWER TRANSMISSION PAD

FIELD

This invention relates to wireless power transfer and more particularly relates to a bi-plane wireless power transfer pad.

BACKGROUND

Wireless power transfer provides a means to direct power across an airgap so that power is transferred from a primary pad to a secondary pad without wired connections. Wireless power transfer is used for providing power to vehicles where a vehicle with a secondary pad may be positioned over a primary pad so that power can be transferred to the vehicle for battery charging or other purposes. Wireless power transfer may also be used to provide power to other items, such as consumer electronics, cellular telephones, etc.

Primary and secondary pads may include ferrite materials in a specific shape and may include charging coils in a particular pattern and shape to shape an electromagnetic field between the pads to increase efficiency and minimize electromagnetic field leakage.

SUMMARY

An apparatus for a bi-plane wireless power transmission pad is disclosed. An alternate apparatus and a system of the apparatus. The apparatus includes a first charging coil with one or more conductors arranged in a first winding pattern and a second charging coil with one or more conductors arranged in a second winding pattern. The apparatus includes a ferrite structure with a main section with a top side, a first side section and a second side section. The first side section and the second side section each include a bottom side where a portion of the top side of the main section is adjacent to a portion of the bottom side of the first side section and the second side section. A portion of the first charging coil and a portion of the second charging coil are positioned adjacent to the top side of the main section interior to where the first side section and the second side section are adjacent to the top side of the main section. A portion of the first charging coil is adjacent to the bottom side of the first side section and a portion of the second charging coil is adjacent to the bottom side of the second side section.

In one embodiment, the main section is magnetically coupled to the first side section and to the second side section. In another embodiment, the apparatus includes a space between the portion of the first charging coil and the portion of the second charging

coil located adjacent to the top side of the main section. In another embodiment, the main section, the first side section and the second side section of the ferrite structure are separate and the top side of the main section is in contact with the bottom side of the first side section and with the bottom side of the second side section. In another embodiment, the portion of the first charging coil and the portion of the second charging coil adjacent to the top side of the main section are wound in a spiral pattern in a plane parallel to the top side of the main section.

In one embodiment, the ferrite structure has a first edge and a second edge, where the first and second edge are located distal to a plane bisecting the main section, the first side section and the second side section, the first charging coil and the second charging coil extend past the first and second edges of the ferrite structure. In another embodiment, the ferrite structure includes a plurality of notches, where each notch accommodates a portion of one of the first charging coil and the second charging coil during a transition between the main section and one of the first side section and the second side section. In another embodiment, the main section is joined to the first side section and the second side section.

In one embodiment, the portion of the first charging coil adjacent to the bottom side of the first side section is wound to group the one or more conductors in a pattern that minimizes conductor length and/or distance from a center point of the main section between the first charging coil and the second charging coil. In another embodiment, the one or more conductors of the first charging coil and the one or more conductors of the second charging coil each include two coils wound in a parallel pattern where a first coil of a charging coil of the first or second charging coils is wound adjacent to a second coil of the charging coil. In another embodiment, each of the one or more conductors of the first charging coil and the second charging coil are stacked in layers over the main section. Each layer is in a plane parallel to the top side of the main section.

In one embodiment, the first and second charging coils and the ferrite structure include a first pad section and the apparatus includes a second pad section. The second pad section has two or more additional charging coils and an additional ferrite structure arranged the same as the first pad section, where the first pad section and the second pad section are arranged to form a charging pad. In another embodiment, the apparatus is part of a primary pad of a wireless power transfer system and the apparatus includes an inverter connected to the first and second charging coils. The inverter injects a signal in the first and second charging coils, where the injected signal generates an

electromagnetic field radiating in a direction away from the top side of the main section. In a further embodiment, the apparatus includes a secondary pad magnetically coupled to the primary pad. The secondary pad converts energy from the electromagnetic field into electrical energy. The apparatus also includes a secondary circuit connected to the secondary pad, where the secondary pad receives the electrical energy from the secondary pad and conditions the electrical energy for use by a load.

An alternate apparatus includes a first charging coil with one or more conductors arranged in a first winding pattern and a second charging coil with one or more conductors arranged in a second winding pattern. The apparatus includes a ferrite structure with a main section with a top side, a first side section and a second side section. The first side section and the second side section each have a bottom side, and the main section is magnetically coupled to the first side section and to the second side section. The ferrite structure is multi-level and the bottom side of the main section is offset from the bottom side of the first side section and from the second side section. A portion of the first charging coil and a portion of the second charging coil are positioned adjacent to the top side of the main section interior to where the first side section and the second side section are adjacent to the top side of the main section. A portion of the first charging coil is adjacent to the bottom side of the first side section and a portion of the second charging coil is adjacent to the bottom side of the second side section.

In one embodiment, the offset is at least a thickness of the first charging coil and/or the second charging coil. The thickness is measured in a direction perpendicular to the bottom side of the first side section and/or the second side section. In another embodiment, the portion of the first charging coil and the portion of the second charging coil adjacent to the top side of the main section are wound in a spiral pattern in a plane parallel to the top side of the main section. In another embodiment, the ferrite structure has a first edge and a second edge. The first and second edges located distal to a plane bisecting the main section, the first side section and the second side section. The first charging coil and the second charging coil extend past the first and second edges of the ferrite structure.

A system for wireless power transfer includes a first charging coil with one or more conductors arranged in a first winding pattern and a second charging coil with one or more conductors arranged in a second winding pattern. The system includes a ferrite structure with a main section with a top side, a first side section and a second side section. The first side section and the second side section each have a bottom side. A

portion of the top side of the main section is adjacent to a portion of the bottom side of the first side section and the second side section, and a portion of the first charging coil and a portion of the second charging coil are positioned adjacent to the top side of the main section interior to where the first side section and the second side section are adjacent to the top side of the main section. A portion of the first charging coil is adjacent to the bottom side of the first side section and a portion of the second charging coil is adjacent to the bottom side of the second side section. The system includes an inverter connected to the first and second charging coils. The inverter injects a signal in the first and second charging coils, where the injected signal generates an electromagnetic field radiating in a direction away from the top side of the main section.

In one embodiment, the first charging coil, the second charging coil and the ferrite structure are part of a primary pad and the system includes a secondary pad magnetically coupled to the primary pad. The secondary pad converts energy from the electromagnetic field into electrical energy. The system includes a secondary circuit connected to the secondary pad, where the secondary circuit receives the electrical energy from the secondary pad and conditions the electrical energy for use by a load.

An apparatus for a wireless power transmission with a magnetic sharing link includes one or more transmitter WPT pads, where each includes one or more coils encircling a ferrite core creating a north pole and a south pole for each WPT pad. The apparatus includes one or more receiver WPT pads, where each includes one or more coils encircling a ferrite core creating a north pole and a south pole for each WPT pad. The one or more transmitter WPT pads and the one or more receiver WPT pads are arranged so that when the one or more receiver WPT pads are aligned over the one or more transmitter WPT pads, each north pole of a transmitter WPT pad is aligned under a south pole of a receiver WPT pad and each south pole of a transmitter WPT pad is aligned under a north pole of a receiver WPT pad.

In one embodiment, each north pole of a transmitter WPT pad is paired with a single south pole of a receiver WPT pad and each south pole of a transmitter WPT pad is paired with a single north pole of a receiver WPT pad. In another embodiment, the one or more transmitter WPT pads include two or more transmitter WPT pads and the one or more receiver WPT pads include two or more receiver WPT pads and the apparatus includes a gap between each of the two or more transmitter WPT pads and a gap between each of the two or more receiver WPT pads. In another embodiment, the gap between the two or more transmitter WPT pads and the gap between the two or more receiver WPT

pads is larger than a gap between the transmitter WPT pads and the receiver WPT pads. In another embodiment, the gap between the two or more transmitter WPT pads and the gap between the two or more receiver WPT pads is at least four times larger than the gap between the transmitter WPT pads and the receiver WPT pads.

5 In one embodiment, the one or more transmitter WPT pads include two or more transmitter WPT pads and the one or more receiver WPT pads include two or more receiver WPT pads and the apparatus includes a distance between the north and south poles of a WPT pad of the two or more transmitter WPT pads and the two or more receiver WPT pads. The distance is greater than a gap between the transmitter WPT pads and the receiver WPT pads. In another embodiment, the distance between the north and south poles of a WPT pad of the two or more transmitter WPT pads and the two or more receiver WPT pads is at least four times the gap between the transmitter WPT pads and the receiver WPT pads. In another embodiment, the one or more transmitter WPT pads include two transmitter WPT pads and the one or more receiver WPT pads two two receiver WPT pads and the two receiver WPT pads are positioned perpendicular to the two transmitter WPT pads.

10 In one embodiment, the one or more transmitter WPT pads include three transmitter WPT pads and the one or more receiver WPT pads include three receiver WPT pads and the three receiver WPT pads are positioned with a first and a second transmitter WPT pads positioned in parallel and a third transmitter WPT pad positioned perpendicular to the first and second transmitter WPT pads and located adjacent to an end of the first and second transmitter WPT pads and the three receiver WPT pads are arranged the same as the three transmitter WPT pads and are oriented 180 degrees from the position of the three transmitter WPT pads during wireless power transfer.

20 In another embodiment, the one or more transmitter WPT pads include four transmitter WPT pads and the one or more receiver WPT pads include four receiver WPT pads and the four transmitter WPT pads are arranged with a first and a second transmitter WPT pads arranged in parallel and a third and a fourth transmitter WPT pads arranged in parallel with the first and second transmitter WPT pads positioned end to end with the third and fourth transmitter WPT pads and the four receiver WPT pads are arranged with a first and a second receiver WPT pads in parallel with a third and a fourth receiver WPT pads arranged perpendicular to the first and second receiver WPT pads where the third receiver WPT pad is located at a first end of the first and second receiver WPT pads and

the fourth receiver WPT pad is located at a second end of the first and second receiver WPT pads, the first end distal to the second end.

In one embodiment, each of the one or more transmitter WPT pads and each of the one or more receiver WPT pads include a first charging coil with one or more conductors arranged in a first winding pattern, and a second charging coil with one or more conductors arranged in a second winding pattern. A portion of the first charging coil and a portion of the second coil are positioned adjacent to a top side and a bottom side of the ferrite structure. In another embodiment, the ferrite structure is a split ferrite structure with a main section with a top side, a first side section and a second side section. The first side section and the second side section each include a bottom side and a portion of the top side of the main section is adjacent to a portion of the bottom side of the first side section and the second side section. A portion of the first charging coil and a portion of the second coil are positioned adjacent to the top side of the main section interior to where the first side section and the second side section are adjacent to the top side of the main section, and a portion of the first charging coil is adjacent to the bottom surface of the first side section and a portion of the second charging coil is adjacent to the bottom surface of the second side section.

In another embodiment, the one or more transmitter WPT pads and the one or more receiver WPT pads are oriented during charging where the first side section and the second side section of each WPT pad are closer than the main section of each WPT pad. In another embodiment, the apparatus includes a gap between the portion of the first charging coil and the portion of the second charging coil located adjacent to the top of the main section. In another embodiment, the main section is magnetically coupled to the first side section and to the second side section. In another embodiment, the portion of the first charging coil and the portion of the second charging coil adjacent to the top surface of the main section are wound in a spiral pattern in a plane parallel to the top surface of the main section. In another embodiment, the one or more conductors of the first charging coil and the one or more conductors of the second charging coil each include two coils wound in a parallel pattern wherein a first coil of a charging coil of the first or second charging coils is wound adjacent to a second coil of the charging coil.

An apparatus for a wireless power transmission with a magnetic sharing link includes two or more transmitter WPT pads, where each transmission WPT pad has one or more coils encircling a ferrite core creating a north pole and a south pole for each WPT pad, and the apparatus includes two or more receiver WPT pads, where each

receiver WPT pad has one or more coils encircling a ferrite core creating a north pole and a south pole for each WPT pad. The apparatus includes a gap between each of the two or more transmitter WPT pads and a gap between each of the two or more receiver WPT pads. The gap between the two or more transmitter WPT pads and the gap between the two or more receiver WPT pads is larger than a gap between the transmitter WPT pads and the receiver WPT pads. The apparatus includes a distance between the north and south poles of a WPT pad of the two or more transmitter WPT pads and the two or more receiver WPT pads, where the distance is greater than a gap between the transmitter WPT pads and the receiver WPT pads. The two receiver WPT pads are positioned perpendicular to the two transmitter WPT pads. The two or more transmitter WPT pads and the two or more receiver WPT pads are arranged so that when the two or more receiver WPT pads are aligned over the two or more transmitter WPT pads, each north pole of a transmitter WPT pad is aligned under a south pole of a receiver WPT pad and each south pole of a transmitter WPT pad is aligned under a north pole of a receiver WPT pad.

In one embodiment, each of the two or more transmitter WPT pads and each of the two or more receiver WPT pads include a first charging coil with one or more conductors arranged in a first winding pattern, and a second charging coil with one or more conductors arranged in a second winding pattern. A portion of the first charging coil and a portion of the second coil are positioned adjacent to a top side and a bottom side of the ferrite structure. The ferrite structure is a split ferrite structure with a main section with a top side, a first side section and a second side section. The first side section and the second side section each have a bottom side and where a portion of the top side of the main section is adjacent to a portion of the bottom side of the first side section and the second side section. A portion of the first charging coil and a portion of the second coil are positioned adjacent to the top side of the main section interior to where the first side section and the second side section are adjacent to the top side of the main section. A portion of the first charging coil is adjacent to the bottom surface of the first side section and a portion of the second charging coil is adjacent to the bottom surface of the second side section.

A system for a wireless power transmission with a magnetic sharing link includes one or more transmitter WPT pads, where each includes one or more coils encircling a ferrite core creating a north pole and a south pole for each WPT pad, and one or more receiver WPT pads, where each includes one or more coils encircling a ferrite core

creating a north pole and a south pole for each WPT pad. The one or more transmitter WPT pads and the one or more receiver WPT pads are arranged so that when the one or more receiver WPT pads are aligned over the one or more transmitter WPT pads. Each north pole of a transmitter WPT pad is aligned under a south pole of a receiver WPT pad and each south pole of a transmitter WPT pad is aligned under a north pole of a receiver WPT pad. The system includes an inverter connected to the one or more charging coils of the transmission WPT pads. The inverter injects a signal in the one or more charging coils, where the injected signal generates an electromagnetic field radiating in a direction away from a top side of the transmission WPT pads.

An apparatus for a wireless power transmission pad with a wired sharing link includes two or more WPT pads, where each WPT pad has two or more charging coils encircling a ferrite core creating a north pole and a south pole for each WPT pad, and a charging coil of a first WPT pad of the two or more WPT pads is wired in series with a charging coil of a second WPT pad of the two or more WPT pads.

In one embodiment, the charging coil of the first WPT pad wired in series is a first charging coil of the first WPT pad and the charging coil of the second WPT pad wired in series is a first charging coil of the second WPT pad and a second charging coil of the first WPT pad is wired in series with a second charging coil of the second WPT pad. In another embodiment, the two or more WPT pads are transmitter WPT pads and the apparatus includes two or more receiver WPT pads where a charging coil of a first receiver WPT pad of the two or more receiver WPT pads is wired in series with a charging coil of a second receiver WPT pad of the two or more receiver WPT pads.

In another embodiment, the charging coil of the first receiver WPT pad wired in series is a first charging coil of the first receiver WPT pad and the charging coil of the second receiver WPT pad wired in series is a first charging coil of the second receiver WPT pad and a second charging coil of the first receiver WPT pad is wired in series with a second charging coil of the second receiver WPT pad. The charging coil of the first transmitter WPT pad wired in series is a first charging coil of the first transmitter WPT pad and the charging coil of the second transmitter WPT pad wired in series is a first charging coil of the second transmitter WPT pad and a second charging coil of the first transmitter WPT pad is wired in series with a second charging coil of the second transmitter WPT pad.

In one embodiment, the two or more WPT pads are transmitter WPT pads and the apparatus includes two or more receiver WPT pads arranged so that when the two or

more receiver WPT pads are aligned over the two or more transmitter WPT pads, each north pole of a transmitter WPT pad is aligned under a south pole of a receiver WPT pad and each south pole of a transmitter WPT pad is aligned under a north pole of a receiver WPT pad. In another embodiment, each receiver WPT pad of the two or more receiver WPT pads is oriented to align with one transmitter WPT pad of the two or more transmitter WPT pads in a same orientation as the one transmitter WPT pad. In another embodiment, each receiver WPT pad of the two or more receiver WPT pads has a north pole and a south pole and the receiver WPT pad is oriented with the north pole to align with a south pole of a transmitter WPT pad of the two or more transmitter WPT pads and the south pole of the receiver WPT pad is oriented to align with a separate transmitter WPT pad of the two or more transmitter WPT pads.

In one embodiment, the two or more WPT pads are two or more receiver WPT pads and the apparatus includes two or more transmitter WPT pads, where each charging coil of the transmitter WPT pads are wired to a separate power supply module and the charging coils of the receiver WPT pads are wired in series are connected to a load. In another embodiment, when the receiver WPT pads are aligned with the transmitter WPT pads, one receiver WPT pad of the two or more receiver WPT pads is aligned with one transmitter WPT pad of the two or more transmitter WPT pads. The north pole of an aligned WPT pad aligns with the south pole of an aligned WPT pad.

In one embodiment, the two or more WPT pads are two or more transmitter WPT pads and the apparatus includes two or more receiver WPT pads, where each charging coil of the receiver WPT pads are wired to a load and the charging coils of the receiver WPT pads are wired in series are connected to a power supply module. In another embodiment, when the receiver WPT pads are aligned with the transmitter WPT pads, one receiver WPT pad of the two or more receiver WPT pads is aligned with one transmitter WPT pad of the two or more transmitter WPT pads. The north pole of an aligned WPT pad aligns with the south pole of an aligned WPT pad. In another embodiment, the charging coil of the first WPT pad and the charging coil of the second WPT pad wired in series each have two or more conductors, where each conductor of the charging coil of the first WPT pad is wired in series with a corresponding conductor of the charging coil of the second WPT pad.

In one embodiment, the apparatus includes a gap between each of the two or more WPT pads. In another embodiment, the two or more WPT pads are two or more transmitter WPT pads and the apparatus includes two or more receiver WPT pads and the

gap between the two or more transmitter WPT pads and the gap between the two or more receiver WPT pads is each larger than a gap between the transmitter WPT pads and the receiver WPT pads. In another embodiment, the two or more WPT pads are two or more transmitter WPT pads and the apparatus includes two or more receiver WPT pads and the apparatus has a distance between the north and south poles of a WPT pad of the two or more transmitter WPT pads and the two or more receiver WPT pads, where the distance is greater than a gap between the transmitter WPT pads and the receiver WPT pads.

In one embodiment, the charging coils of each of the two or more WPT pads include a first charging coil with one or more conductors arranged in a first winding pattern, and a second charging coil with one or more conductors arranged in a second winding pattern. A portion of the first charging coil and a portion of the second charging coil are positioned adjacent to a top side and a bottom side of the ferrite structure. In another embodiment, the ferrite structure is a split ferrite structure with a main section with a top side, a first side section and a second side section. The first side section and the second side section each have a bottom side and a portion of the top side of the main section is adjacent to a portion of the bottom side of the first side section and the second side section. A portion of the first charging coil and a portion of the second coil are positioned adjacent to the top side of the main section interior to where the first side section and the second side section are adjacent to the top side of the main section. A portion of the first charging coil is adjacent to the bottom surface of the first side section and a portion of the second charging coil is adjacent to the bottom surface of the second side section. In another embodiment, the portion of the first charging coil and the portion of the second charging coil adjacent to the top surface of the main section are wound in a spiral pattern in a plane parallel to the top surface of the main section.

An apparatus for a wireless power transmission pad with a wired sharing link includes two or more WPT pads, where each WPT pad has two or more charging coils encircling a ferrite core creating a north pole and a south pole for each WPT pad. A first charging coil of a first WPT pad of the two or more WPT pads is wired in series with a first charging coil of a second WPT pad of the two or more WPT pads. A second charging coil of the first WPT pad is wired in series with a second charging coil of the second WPT pad.

A system for a wireless power transmission pad with a wired sharing link includes two or more transmitter WPT pads, where each transmitter WPT pad has two or more charging coils encircling a ferrite core creating a north pole and a south pole for each

transmitter WPT pad. A first charging coil of a first transmitter WPT pad of the two or more transmitter WPT pads is wired in series with a first charging coil of a second transmitter WPT pad of the two or more transmitter WPT pads, and a second charging coil of the first transmitter WPT pad is wired in series with a second charging coil of the second transmitter WPT pad. The system includes two or more receiver WPT pads, where each receiver WPT pad has two or more charging coils encircling a ferrite core creating a north pole and a south pole for each receiver WPT pad. A first charging coil of a first receiver WPT pad of the two or more receiver WPT pads is wired in series with a first charging coil of a second receiver WPT pad of the two or more receiver WPT pads. A second charging coil of the first receiver WPT pad is wired in series with a second charging coil of the second receiver WPT pad. The system includes one or more inverters connected to the two or more charging coils of the transmission WPT pads. The inverter injects a signal in the two or more charging coils, where the injected signal generates an electromagnetic field radiating in a direction away from a top side of the transmission WPT pads.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that the advantages of the invention will be readily understood, a more particular description of the invention briefly described above will be rendered by reference to specific embodiments that are illustrated in the appended drawings. Understanding that these drawings depict only typical embodiments of the invention and are not therefore to be considered to be limiting of its scope, the invention will be described and explained with additional specificity and detail through the use of the accompanying drawings, in which:

Figure 1 illustrates a block diagram of an exemplary inductive power transfer (“IPT”) charging system;

Figure 2A depicts a top view of a first embodiment of a bi-plane wireless power transfer pad;

Figure 2B depicts a top view of a second embodiment of a bi-plane wireless power transfer pad;

Figure 2C depicts a top view of a third embodiment of a bi-plane wireless power transfer pad;

Figure 2D depicts a top view of a fourth embodiment of a bi-plane wireless power transfer pad with two conductors per charging coil;

Figure 3A depicts a side section view of one embodiment of a wireless power transfer pad with charging coils in one plane;

Figure 3B depicts a solenoid with a ferrite structure with a charging coil wrapped around the ferrite structure;

5 Figure 3C depicts a solenoid with a ferrite structure with two charging coils wrapped around the ferrite structure;

Figure 3D depicts a side section view of one embodiment of a wireless power transfer pad with a uniform ferrite structure and charging coils extending above and below the ferrite structure;

10 Figure 3E depicts a side section view of one embodiment of a wireless power transfer pad with a bi-plane ferrite structure and accompanying charging coils extending above and below sections of the ferrite structure;

Figure 3F depicts a side section view of another embodiment of a wireless power transfer pad with a bi-plane ferrite structure and accompanying charging coils extending above and below sections of the ferrite structure, where a portion of the charging coils are adjacent;

15 3G depicts a side section view of another embodiment of a wireless power transfer pad with a bi-plane ferrite structure and accompanying charging coils extending above and below sections of the ferrite structure, where a portion of the charging coils are bundled;

Figure 4 depicts a top view of another embodiment of a bi-plane wireless power transfer pad using a square winding pattern;

Figure 5 depicts a top view of another embodiment of a bi-plane wireless power transfer pad with four charging coils arranged in an X pattern;

25 Figure 6 depicts a top view of another embodiment of a bi-plane wireless power transfer pad with four charging coils arranged in a side-by-side pattern;

Figure 7 depicts a side section view of a primary pad and a secondary pad with bi-plane ferrite structures;

Figure 8 is a perspective view of one embodiment of an apparatus with two bi-plane transmitter WPT pads under two bi-plane receiver WPT pads on top configured with a magnetic sharing link;

Figure 9 is a perspective view of the embodiment of Figure 8 including a magnetic flux path;

Figure 10 is a perspective view of one embodiment of an apparatus with four bi-plane WPT pads configured in a partial magnetic flux sharing configuration and including two magnetic flux paths;

Figure 11 is a top view of top and bottom WPT pads for a two pad, a four pad, a six pad and an eight pad configuration, all configured for magnetic flux sharing;

Figure 12A is a top view of a schematic block diagram of an apparatus with two top WPT pads and two bottom WPT pads where the top and bottom WPT pads have a ferrite structure that extends beyond where the WPT pads overlap;

Figure 12B is a top view of a schematic block diagram of an apparatus with two top WPT pads and two bottom WPT pads where the top and bottom WPT pads have a ferrite structure that extends beyond where the WPT pads overlap and alignment of the top WPT pads are offset from the center;

Figure 13 is a top view of a WPT pad apparatus with charging coils of WPT pads wired in series; and

Figure 14 is a schematic diagram an apparatus 1400 depicting side views of transmitter and receiver WPT pads where the receiver WPT pads are wired in series and the transmitter WPT pads each have a separate power supply module.

DETAILED DESCRIPTION

Reference throughout this specification to “one embodiment,” “an embodiment,” or similar language means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment. Thus, appearances of the phrases “in one embodiment,” “in an embodiment,” and similar language throughout this specification may, but do not necessarily, all refer to the same embodiment, but mean “one or more but not all embodiments” unless expressly specified otherwise. The terms “including,” “comprising,” “having,” and variations thereof mean “including but not limited to” unless expressly specified otherwise. An enumerated listing of items does not imply that any or all of the items are mutually exclusive and/or mutually inclusive, unless expressly specified otherwise. The terms “a,” “an,” and “the” also refer to “one or more” unless expressly specified otherwise.

Furthermore, the described features, structures, or characteristics of the invention may be combined in any suitable manner in one or more embodiments. In the following description, numerous specific details are provided, such as examples of programming, software modules, user selections, network transactions, database queries, database structures, hardware modules, hardware circuits, hardware chips, etc., to provide a

thorough understanding of embodiments of the invention. One skilled in the relevant art will recognize, however, that the invention may be practiced without one or more of the specific details, or with other methods, components, materials, and so forth. In other instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring aspects of the invention.

The schematic flow chart diagrams included herein are generally set forth as logical flow chart diagrams. As such, the depicted order and labeled steps are indicative of one embodiment of the presented method. Other steps and methods may be conceived that are equivalent in function, logic, or effect to one or more steps, or portions thereof, of the illustrated method. Additionally, the format and symbols employed are provided to explain the logical steps of the method and are understood not to limit the scope of the method. Although various arrow types and line types may be employed in the flow chart diagrams, they are understood not to limit the scope of the corresponding method. Indeed, some arrows or other connectors may be used to indicate only the logical flow of the method. For instance, an arrow may indicate a waiting or monitoring period of unspecified duration between enumerated steps of the depicted method. Additionally, the order in which a particular method occurs may or may not strictly adhere to the order of the corresponding steps shown.

Figure 1 depicts a schematic block diagram of one embodiment of an IPT charging system 100 for wireless power transfer. Figure 1 illustrates a block diagram of an exemplary inductive power transfer (“IPT”) charging system 100. The IPT charging system 100 of Figure 1 is one embodiment of a system 100 that may include an IPT system 102, as described below. In other embodiments, the IPT system 102 may be used for purposes other than for charging. The IPT system 102 includes a first stage 104, a second stage 106, and wireless power transfer between the first stage 104 and second stage 106 over an air gap 108. The system 100 includes a load 110 and a voltage source 112. The elements of the IPT charging system 100 are described below.

The IPT charging system 100 includes, in one embodiment, a first stage 104 with an LCL (i.e. inductor-capacitor-inductor) load resonant converter 118 that receives a direct current (“DC”) voltage 116 and generates an alternating current (“AC”) voltage waveform in the primary pad 126. For example, a switching section may alternatively connect the DC voltage 116 to an LCL load resonant section at a particular frequency to generate an AC voltage waveform. The AC voltage waveform, in some embodiments, is

not a pure sinusoidal waveform and includes harmonic voltages. Filtering in the LCL load resonant converter 118 may reduce harmonic content.

The AC voltage waveform and associated current are transmitted to the primary pad 126, which generates an electromagnetic waveform shaped by the design of the primary pad 126 to radiate in a direction toward the secondary pad 128. Through magnetic coupling, an electromagnetic waveform is induced in the secondary pad 128 and generates an AC electrical waveform in the secondary pad 128. The electrical waveform, with a particular voltage waveform and current waveform, in the secondary pad 128 transfers power to the secondary circuit 130, which may condition the voltage and current for use by a load 110, such as a battery 138, electric motor, etc. The secondary circuit may include a rectifier section and may also include a DC-DC converter, or similar circuit to regulate voltage and/or current to the load 110. The second stage 106 and load 110 may be part of a vehicle 140.

The primary controller 120 controls the LCL load resonant converter 118 and the secondary decoupling controller 132 controls the secondary circuit 130. The IPT charging system 100 may also include one or more sensors for position detection 122. While the sensors for position detection 122 is shown in the first stage 104, one of skill in the art will recognize that all or part of the sensors for position detection 122 may be located in the second stage 106, on the vehicle 140, or elsewhere in the IPT system 102. In one embodiment, the IPT charging system 100 includes wireless communications 124, 134 that provide for communication between the first stage 104 and the second stage 106. Wireless communication may be used for control, position sensing, identification, and the like.

The IPT charging systems 100 described herein may include a power factor stage 114, such as a primary alternating current ("AC") to direct current ("DC") power factor stage, fed from a voltage source 112, such as from a utility power grid. In some embodiments, a primary AC-DC converter stage may be configured to convert grid-level voltages to a DC voltage 116, such as a DC bus voltage, for a primary tuned resonant converter. A DC output voltage with low output ripple is preferred to large ripple systems in order to prevent an amplitude modulated signal appearing in the wireless inductive power transfer system which can cause reduced efficiency and require additional complexity.

In some embodiments, active power factor correction ("PFC") in AC-DC converters may help to ensure the grid voltage and current are closely in phase. PFC may

reduce overall grid current requirements and typically reduces grid harmonics (i.e. the grid represented by the voltage source 112). Grid power supply companies typically have certain harmonic requirements for attached industrial equipment. Often grid power supply companies also charge extra for power to industrial equipment that exhibits low power factor.

In the IPT charging system 100 described herein, one or more suitable stages may be used for PFC. For example, one or more commercial off-the-shelf (“COTS”) AC-DC high efficiency power factor corrected converters may be used. The grid voltage source 112 may be a wide range of voltage inputs including, for example, single-phase 240 VAC, three-phase 208 VAC, or three-phase 480 VAC. In another embodiment, a 400 VDC output may be used for this stage and 400 VDC is typically an efficient output for a nominal grid input of single-phase 240 VAC grid input. A single-phase 240 VAC grid voltage with a 30 A circuit (suitable for a 5 kW IPT system) is commonplace in the United States even in areas that do not support industrial three-phase voltages, and may be used with the IPT charging system 100.

For the IPT charging system 100, in one embodiment, the first stage 104 includes an LCL load resonant converter 118 controlled by a primary controller 120 that may receive feedback signals from and may send control signals to the LCL load resonant converter 118. A primary controller 120 may receive information from alignment sensors for position detection 122 and may communicate using wireless communications 124. The LCL load resonant converter 118 is coupled to a primary pad 126 coupled to a secondary pad 128 over an air gap 108.

While an air gap 108 is depicted, one of skill in the art will recognize that at least a portion of the space between the primary pad 126 and the secondary pad 128 include other materials and substances, such as concrete, resin, asphalt, metal, and the like. The secondary pad 128 is connected to a parallel decoupling pickup shown as a secondary circuit 130 controlled by a secondary decoupling controller 132 that may receive feedback signals and may send control signals to the secondary circuit 130. The secondary decoupling controller 132 may also communicate with alignment sensors for position detection 136 for control and may communicate wirelessly 134. The secondary circuit 130 may connect to a load 110, such as a battery 138 and may charge the battery 138. The battery 138 may provide power to another load, such as a motor controller (not shown). The second stage 106 and load 110 may be located in a vehicle 140.

Other embodiments of an IPT system 102 may include wireless power transfer for other purposes, such as battery charging and power for consumer electronic devices, such as a cellular phone, an electric razor, an electric toothbrush, and the like. One of skill in the art will recognize other uses for wireless power transfer and other IPT systems.

5 Figure 2A depicts a top view of a first embodiment of a bi-plane wireless power transfer (“WPT”) pad 200A. The WPT pad 200A may be a primary pad 126 or a secondary pad 128. The WPT pad 200A includes a first charging coil 202 with one or more conductors arranged in a first winding pattern and a second charging coil 204 with one or more conductors arranged in a second winding pattern. In the embodiment, a
10 portion of the second charging coil 204 is positioned adjacent to a portion of the first charging coil 202. In one example, each of the first charging coil 202 and the second charging coil 204 include one conductor. Other embodiments of WPT pads (e.g. 200B, 201) may also include charging coils 202, 204 with one conductor. The conductor may be wound in a spiral pattern so that if a loop starts at an interior location each successive
15 loop is adjacent to the previous loop in an ever increasing spiral. The spiral pattern may be similar to an Archimedean spiral or an arithmetic spiral. In one embodiment, a conductor of each of the first charging coil 202 and the second charging coil 204 have a portion that is in a same plane. Other embodiments may include a first charging coil 202 and a second charging coil 204 where each includes two or more conductors. The two or
20 more conductors may be wound in parallel, as depicted in the WPT pad 203 of Figure 2D.

 The WPT pad 200A, in one embodiment, includes a multi-level ferrite structure that includes a main section 206 with a top side, a first side section 208 and a second side section 210 where each side section 208, 210 includes a bottom side. In one
25 embodiment, a portion of the top side of the main section 206 is adjacent to a portion of the bottom side of the first side section 208 and the second side section 210. In the embodiment, having the portion of the top side section 208 adjacent to the portion of the bottom side of the first side section 208 and second side section 210 includes the top side of the main section 206 being coplanar to the bottom side of the first side section 208 and
30 the second side section 210. For example, a portion of the bottom side of the first side section 208 and/or the second side section 210 may touch the top side of the main section 206. In other embodiments, the bottom side of the first side section 208 and second side section 210 may be offset from the bottom of the main section 206 and may be higher or lower than the top side of the main section 206.

The bottom side of the first side section 208 and the bottom side of the second side section 210, in the embodiment, are not coplanar with a bottom side of the main section 206, but are instead raised with respect to a plane of the bottom side of the first and second side sections 208, 210 by an offset. In one embodiment, the offset is at least a thickness of the first charging coil 202 and/or the second charging coil 204 where the thickness is measured in a direction perpendicular to the bottom side of the first side section 208 and/or the second side section 210.

In the embodiment depicted in Figure 2A, a portion of the first charging coil 202 and the portion of the second charging coil 204 that are adjacent to the main section 206 are positioned on the top side of the main section 206. For example, the bottom side of the first side section 208 and/or the second side section 210 may be in contact with the top side of the main section 206. Also, a portion of the first charging coil 202 is adjacent to the bottom side of the first side section 208 and a portion of the second charging coil 204 is adjacent to the bottom side of the second side section 210. Having the bottom side of the first side section 208 and the bottom side of the second side section 210 raised with respect to a plane of the bottom side of the first and second side sections 208, 210 allows that the first charging coil 202 and the second charging coil 204 to have a portion adjacent to the first side section 208 and second side section 210 elevated with respect to the plane of the bottom side of the main section 206, which typically provides for a thinner WPT pad 200A than a flat ferrite structure, as depicted in Figure 3D. Arrangement of the first charging coil 202, the second charging coil 204, the main section 206, the first side section 208, and the second side section 210 are depicted in a side section view in Figure 3F.

By arranging two coils (e.g. 202, 204) to be adjacent, the electromagnetic field formed above the first and second charging coils 202, 204 may be additive where current is circulated in the first and second charging coils 202, 204 so that the electromagnetic field formed by each of the first and second charging coils 202, 204 are directed upward, in a direction perpendicular to the main section 206 in a direction from the main section 206 toward the portion of the first and second charging coils 202, 204 that are adjacent. In looking at Figure 2A, the electromagnetic field would be directed out of the page toward the viewer, as depicted in Figures 3D-3G by the dashed lines 316, 318. Over the portions of the first and second charging coils 202, 204 that are adjacent, the resulting electromagnetic flux pattern 318 may be increased compared to the electromagnetic fields 316 of the first and second charging coils 202, 204.

Portions of the first and second charging coils 202, 204 extending below the first and second side sections 208, 210 may generate an electromagnetic field with a portion that is directed downward, which may be unusable for charging with regard to wireless power transfer to a secondary pad 128. Directing this portion of the electromagnetic field below the first and second side sections 208, 210 downward may be advantageous so that this portion of the electromagnetic field may be directed toward the earth or away from users.

In the embodiment depicted in Figure 2A, the portions of the first and second charging coils 202, 204 that are below the first and second side sections 208, 210 are depicted as spread out and may be in a plane adjacent to a bottom side 312 of the first and second side sections 208, 210. Maintaining the conductors of the first and second charging coils 202, 204 side-by-side under the first and second side sections 208, 210 may be unnecessary because shaping an electromagnetic field in a downward direction may not be useful and may require side sections 208, 210 that are larger than necessary. The WPT pad 201 depicted in Figure 2B depicts the portions of the first and second charging coils 202, 204 that are below the first and second side sections 208, 210 as bunched together. As depicted in Figure 3G, bunching the conductors may include multiple layers of conductors (see 310). Bunching the conductors of the first and second charging coils 202, 204 on the bottom of the first and second side sections 208, 210 may serve to reduce the size of the first and second side sections 208, 210. While the portions of the first and second charging coils 202, 204 below the first and second side sections 208, 210 will generate some electromagnetic field, bunching the conductors may serve to reduce conductor length, reduce the size of the ferrite structure, and may result in an electromagnetic field around the bunched conductors that is not shaped in a particular direction where shaping is not needed.

The main section 206 of the ferrite structure in the WPT pads 200A, 200B of Figures 2A and 2B include a tab section 212 that extends under the first and second side sections 208, 210. The tab sections 212 in one embodiment, allow the first and second side sections 208, 210 to be magnetically coupled to the main section 206 and may provide a convenient surface for the first and second side sections 208, 210 to contact the main section 206. Note that the tab sections 212 are depicted as a particular width that is less than the inner-most winding of the first and second charging coils 202, 204. A notch 214 is formed to the sides of the tab section 212, which may be a convenient location for the first and second charging coils 202, 204 to transition from the top side of the main

section 206 to the bottom side of the first and second side sections 208, 210. As winding patterns vary, one of skill in the art will recognize other widths for the tab sections 212 and associated notches 214. The first and second winding patterns may also vary depending on shaping requirements of a desired electromagnetic field.

5 Figure 2C depicts a top view of a third embodiment of a bi-plane wireless power transfer pad 201. The WPT pad 201 includes a first charging coil 202 and second charging coil 204, each with one conductor. The ferrite structure of the WPT pad 201 includes a main section 206, a first side section 208, and a second side section 210 which are each rectangular (or square) and the main section 206 does not include tab sections 212. The first and second charging coils 202, 204 wrap around edges 216 of the main
10 section 206, as depicted in Figure 3E.

 The first and second charging coils 202, 204, in one embodiment, extend a distance beyond the edges 216 of the main section 206 to accommodate a finite bending radius of the conductors and to accommodate a structure used to maintain position of the
15 first and second charging coils 202, 204 and may be wrapped closer than depicted in Figure 3C where a conductor is used with a tighter bending radius or a structure maintaining position of the first and second charging coils 202, 204 is more flexible, smaller, etc. By winding the first and second charging coils around the ferrite structure, the WPT pads 200A, 200B, 201 more closely match a solenoid, which may provide
20 stronger magnetic fields than a WPT pad with charging coil(s) on a top side.

 Figure 2D depicts a top view of a fourth embodiment of a bi-plane wireless power transfer pad 203 with two conductors per charging coil. The WPT pad 203 of Figure 2D is similar to the WPT pad 201 of Figure 2C where the ferrite structures of the WPT pads 201, 203 are the same but the first and second charging coils 202, 204 each have two
25 conductors wound in parallel. Having two conductors in parallel allow connection of the conductors in parallel, which decreases an amount of voltage required to be applied to the WPT pad 203, as described in U.S. Patent Application No. 62186257, filed June 29, 2015 for Patrice Lethellier, et al., which is herein incorporated by reference for all purposes.

 Figure 3A depicts a side section view of one embodiment of a wireless power transfer pad 300 with first and second charging coils 202, 204 in one plane. Figure 3A depicts another embodiment that serves to illustrate an alternate design. In the
30 embodiment, a portion 308 of the first and second charging coils 202, 204 are adjacent. In the design depicted in Figure 3A, two coils are positioned on top of a single, planar ferrite structure 304. Each of the first and second charging coils 202, 204 generate a

magnetic field 316 shaped to radiate upward, away from the ferrite structure 304 so that a resulting electromagnetic flux pattern 318 that extends higher than each of the first and second charging coils 202, 204 alone.

However, the portions of the first and second charging coils 202, 204 away from the center also generate electromagnetic flux 320 and don't readily combine with each other so that only the portion over the adjacent sections combine to form a heightened electromagnetic flux pattern 318. In addition, the first and second charging coils 202, 204 do not wrap around the ferrite structure, so generated magnetic flux is less than other designs that wrap around the ferrite structure. The electromagnetic flux 320 over the portion of the first and second charging coils 202, 204 don't contribute in any significant way to power transfer to the secondary pad 128 and are typically unwanted. Leakage electromagnetic flux may make it more difficult to comply with regulations and may require shielding, barriers to keep people away, etc. Elimination or minimization of the leakage electromagnetic flux, such as the electromagnetic flux 320 in Figure 3A is beneficial in many circumstances.

Figure 3B depicts a solenoid 301A with a ferrite structure 304 and a charging coil 322 wrapped around the ferrite structure 304. The ferrite structure 304 and charging coil 322 are in the form of a typical solenoid 301A. Wrapping the charging coil 322 around the ferrite structure 304 provides a strong electromagnetic field 324 with a north pole at one end and a south pole at the other end. The electromagnetic field 324 is affected by the shape of the ferrite structure 304 and charging coil 322. The ferrite structure 304 may be shaped as a rectangular prism with a top side that is planar, as depicted in the main section 206 of the WPT pad 201 of Figure 2C, or in other shapes.

Figure 3C depicts another solenoid 301B with ferrite structure 304 and two charging coils 326, 328 wrapped around the ferrite structure 304. By splitting the charging coil 322 of the solenoid 301A of Figure 3B into two charging coils 326, 328, the north and south poles may be spread apart, which may then form an electromagnetic field 330 that extends further from the ferrite structure 304 than the electromagnetic field 324 of the solenoid 301A of Figure 3B.

Figure 3D depicts a side section view of one embodiment of a wireless power transfer pad 301C with a uniform ferrite structure 304 and a charging coil extending above and below the ferrite structure 304. By wrapping the first and second charging coils 202, 204 around to the bottom side of the ferrite structure 304 or by feeding the first and second charging coils 202, 204 through gaps (not shown) in the ferrite structure 304,

a portion 310 of the first and second charging coils 202, 204 are below the bottom side 312 of the ferrite structure 304 and radiate electromagnetic flux 332 in a downward away from the bottom side 312 of the ferrite structure 304. Thus, the unwanted electromagnetic flux 320 of the WPT pad 300 of Figure 3A is modified for the WPT pad 301C of Figure 3D so that the unwanted electromagnetic flux 332 radiates downward, which may be more easily controllable. For example, at least a portion of the unwanted electromagnetic flux 332 may be directed into the earth where the WPT pad 301C is ground mounted. In other embodiments, shielding or measures may be taken under the WPT pad 301C to minimize impact. A disadvantage of the design of the WPT pad 301C depicted in Figure 3D is that the WPT pad 301C has the added thickness of the portion 310 of the first and second charging coils 202, 204 and any associated support structure for the first and second charging coils 202, 204. Adding thickness to a WPT pad (e.g. 300, 301C) may be inconvenient.

Figure 3E depicts a side section view (e.g. modified section A-A' of Figure 2C) of one embodiment of a wireless power transfer pad 302A with a bi-plane ferrite structure and accompanying charging coils 202, 204 extending above and below sections of the ferrite structure. Like the WPT pad 301C of Figure 3D, a portion 310 of the first and second charging coils 202, 204 extend below the ferrite structure. However, the ferrite structure is modified to include a main section 206, a first side section 208 and a second side section 210 as depicted in the WPT pads 200A, 200B, 201, 203 of Figures 2A-2D. By placing the first and second side sections 208, 210 above the main section 206 as depicted, or at least elevated with respect to the main section 206, where the portions 310 below the first and second side sections 208, 210 are lifted above where they are located in the WPT pad 301C of Figure 3D, the overall thickness of the WPT pad 302A of Figure 3E can be made to be thinner than the WPT pad 301C of Figure 3D. In addition, at least a portion of the unwanted electromagnetic flux 332 is again directed downward, away from the bottom of the first and second side sections 208, 210.

In one embodiment, such as depicted for the WPT pads 200A, 200B of Figure 2A, 2B, the first and second charging coils 202, 204 may be routed through notches 214 adjacent to the tab section 212 of the main section 206. Routing the first and second charging coils 202, 204 through the notches 214 may be a convenient way to maintain the shape of the portion 308 of the first and second charging coils 202, 204 over the main section 206 while allowing the first and second charging coils 202, 204 to transition to the bottom 312 of the first and second side sections 208, 210. While the path of the first

and second charging coils 202, 204 are depicted as straight, one of skill in the art will recognize that the first and second charging coils 202, 204 may bend to be routed through the notches 214.

In another embodiment, such as depicted in the WPT pads 201, 203 of Figures 2C and 2D, the first and second charging coils 202, 204 may be routed around the edges 216 of the main section 206. Routing the first and second charging coils 202, 204 around the edges 216 of the main section 206 may allow for a more compact ferrite structure than is depicted in the WPT pads 200A, 200B of Figures 2A and 2B. For clarity, routing of the first and second charging coils 202, 204 from above the main section 206 to below the first and second side sections 208, 210 is not depicted except for a single conductor 334 for each charging coil 202, 204.

Figure 3F depicts a side section view of another embodiment of a wireless power transfer pad 302B with a bi-plane ferrite structure and accompanying first and second charging coils 202, 204 extending above and below sections of the ferrite structure, where a portion of the first and second charging coils 202, 204 are adjacent. The ferrite structure of the WPT pad 302B may be similar to the ferrite structure of the WPT pad 302A, except the main section 206 may be smaller so that the overall width of the WPT pad 302A may be less than the WPT pad 302A of Figure 3E. A smaller main section 206 with first and second charging coils 202, 204 may have an electromagnetic flux pattern 318 above the main section 206 that is less than where the first and second charging coils 202, 204 are split, but may provide a more compact design. In other embodiments, reducing a space between the first and second charging coils 202, 204 may be the result of adding additional wraps to the first and second charging coils 202, 204. One of skill in the art will recognize other designs with and without a space between the first and second charging coils 202, 204.

Figure 3G depicts a side view of another embodiment of a wireless power transfer pad 303 with a bi-plane ferrite structure and accompanying first and second charging coils 202, 204 extending above and below sections of the ferrite structure, where a portion 310 of the charging coils are bundled. Where the electromagnetic flux 332 below the first and second side sections 208, 210 and is unwanted, maintaining the portions 310 of the first and second charging coils 202, 204 in a plane may be unnecessary. To reduce a width of the ferrite structure, the portions 310 of the first and second charging coils 202, 204 below the first and second side sections 208, 210 may be bundled so that the first and second side sections 208, 210 may be shortened in width. The unwanted electromagnetic

flux 332 from the portions 310 of the first and second charging coils 202, 204 below the first and second side sections 208, 210 will be shaped differently, which may be unimportant.

Note that shaping of the portions 308 of the first and second charging coils 202, 204 may be used to shape the electromagnetic flux pattern 318 above the ferrite structure. The types of conductors, the spacing of the conductors, the routing of the conductors, etc. may be used to modify the electromagnetic flux pattern 318 above the ferrite structure.

Figure 4 depicts a top view of another embodiment of a bi-plane wireless power transfer pad 400 using a square winding pattern. The WPT pad 400 depicts another way to wind a first charging coil 402 and a second charging coil 404 that changes the shape of the electromagnetic flux above the WPT pad 400. The square pattern may create electromagnetic flux that is more even along an axis between the first and second charging coils 402, 404.

Figure 5 depicts a top view of another embodiment of a bi-plane wireless power transfer pad 500 with four charging coils 502 arranged in an X pattern. A ferrite structure associated with the WPT pad 500 includes a main section 504 and side sections 506, 508, 510, 512 that are similar to those depicted in the WPT pads 201, 303 of Figures 2A and 3D, but include additional charging coils 502 and side sections 510, 512. While “D” shaped charging coils 502 are depicted, other charging coil designs may be used. For example, the charging coils 502 may be shaped with a pointed portion directed to a center of the main section 504. The charging coils 502 may be connected to each produce an electromagnetic field above the main section 504 in a direction away from a top side of the main section 504. However, the X pattern may not be as efficient for sharing flux between coils as other designs.

Figure 6 depicts a top view of another embodiment of a bi-plane wireless power transfer pad 600 with four charging coils 602 arranged in a side-by-side pattern. Like the WPT pad 500 of Figure 5, the WPT pad 600 of Figure 6 includes a ferrite structure with a main section 604, and side sections 606, 608, 610, 612. The WPT pad 600 includes charging coils 602 in a square winding pattern, which may more efficiently fill a space above a main section 604 to produce a more uniform electromagnetic field than “D” shaped winding patterns or other winding patterns.

In another embodiment (not shown), the ferrite structure of the WPT pads 201, 203 may be used with a square winding pattern. In another embodiment, the ferrite structure may be split (e.g. along line 614) so that two WPT pads 200B of Figure 2B are

provided. In another embodiment, the ferrite structure may be split (e.g. along line 614) with a gap in between so that two WPT pads 201 of Figure 2C are provided. In the embodiment, the first and second charging coils 202, 204 may extend beyond the edges 216 of the main section 206. In another related embodiment, the WPT pads 201 may be part of a primary pad 126 and two additional WPT pads 201 may form a secondary pad 128. In one example, the WPT pads 201 of the secondary pad 128 may be positioned perpendicular to the WPT pads 201 of the primary pad 126 forming a square shape where magnetic flux may be shared efficiently in a ring pattern.

As with the WPT pad 303 of Figure 3G, the portions of the charging coils 602 under the side sections 606, 608, 610, 612 may be bundled or otherwise compacted. One of skill in the art will recognize other winding patterns with multiple charging coils and a bi-plane ferrite structure. For example, a WPT pad may include three charging coils, five charging coils, coils two or more conductors wound together and connected in parallel, etc.

Figure 7 depicts a side section view of a primary pad 126 and a secondary pad 128 with bi-plane ferrite structures. The primary pad 126 and the secondary pad 128 may be similar to the WPT pad 201 of Figure 2C where the secondary pad 128 is inverted. A magnetic flux path 702 is depicted showing how magnetic flux runs through the ferrite structure of the primary pad 126, up through an air gap 108 at one end, through the ferrite structure of the secondary pad 128 and through the air gap 108 at the other end. The magnetic flux lines are not complete and are only intended to depict a pathway for magnetic flux. One of skill in the art will recognize other details of an electromagnetic field formed between the primary pad 126 and the secondary pad 128.

In one embodiment, an apparatus for wireless power transfer includes one or more transmitter WPT pads and one or more receiver WPT pads (e.g. 200A, 200B, 201, 203, 301C, 302A, 302B, 303, 400). Each WPT pad (e.g. 200A, 200B, 201, 203, 301C, 302A, 302B, 303, 400) includes one or more coils (e.g. 202, 204) encircling a ferrite core (e.g. 206, 208, 210, 304) creating a north pole and a south pole for each WPT pad. The one or more transmitter WPT pads and the one or more receiver WPT pads are arranged so that when the one or more receiver WPT pads are aligned over the one or more transmitter WPT pads, each north pole of a transmitter WPT pad is aligned under a south pole of a receiver WPT pad and each south pole of a transmitter WPT pad is aligned under a north pole of a receiver WPT pad.

As one example, Figure 8 is a perspective view of one embodiment of and apparatus 800 with four bi-plane WPT pads configured in a partial magnetic flux sharing configuration and including two magnetic flux paths 806, 808. The apparatus 800 includes two transmitter WPT pads 802 positioned in parallel and two receiver WPT pads 804 positioned over the transmitter WPT pads 802. In the apparatus 800, there is partial magnetic flux sharing where a single transmitter WPT pad 802 and a single receiver WPT pad 804 share magnetic flux. While the apparatus 800 may allow for a more flexible arrangement of WPT pads, for example in-line, there is a higher probability of unequal power sharing, which may require other electronics to ensure equal power sharing.

As another example, Figure 9 is a perspective view of one embodiment of an apparatus 900 with two transmitter bi-plane WPT pads 902 under two bi-plane receiver WPT pads 904 on top configured with a magnetic sharing link. Each WPT pad 902, 904 includes a north pole “N” and a south pole “S” where a north pole N of a WPT pad (e.g. transmitter pad 902) is aligned with a south pole S of another WPT pad (e.g. receiver pad 904). Typically, as depicted in Figure 7, the receiver WPT pad 904 is up-side-down compared to the transmitter WPT pad 902. Figure 10 is a perspective view of the one embodiment of the apparatus 900 of Figure 9 including a magnetic flux path 906. In one embodiment, each north pole N of a transmitter WPT pad 902 is paired with a single south pole S of a receiver WPT pad 904 and each south pole S of a transmitter WPT pad 902 is paired with a single north pole N of a receiver WPT pad 904. Notice that the magnetic flux path transverses through the ferrite cores of the WPT pads 902, 904 and then vertically through an air gap 128 from a north pole N to a south pole S (see the darker dashed line of the magnetic flux path 906).

Note that the depicted magnetic flux path 906 is idealized and that some leakage may occur outside of the north/south pole transitions. Where there are two or more transmitter WPT pads 902 and two or more receiver WPT pads 904, in one embodiment there is a gap 908 between the transmitter WPT pads 902 and a gap 910 between the receiver WPT pads 904. Having a gap between WPT pads 902, 904 that is relatively large in comparison to the air gap 128 helps to reduce leakage flux between the north pole N and the south pole S of a WPT pad 902, 904. In one embodiment, the gaps 908, 910 between WPT pads 902, 904 is more than two times the air gap 128. In another embodiment, to reduce leakage flux even further, the gap 908 between the two or more transmitter WPT pads 902 and the gap 910 between the two or more receiver WPT pads 904 is at least four times larger than a gap 128 between the transmitter WPT pads 902

and the receiver WPT pads 904. One of skill in the art will recognize a reasonable ratio between gaps 908, 910 between WPT pads 902, 904 and an air gap 128 to minimize flux leakage.

In another embodiment, where the apparatus (e.g. 900) includes two or more transmitter WPT pads 902 and two or more receiver WPT pads 904, a distance (e.g. 912) between the north and south poles of a WPT pad of the two or more transmitter WPT pads 904 and the two or more receiver WPT pads 904 is greater than a gap 128 between the transmitter WPT pads 902 and the receiver WPT pads 904. For example, the distance 912 may be more than two times the air gap 128. In another embodiment, the distance 912 between the north and south poles of a WPT pad of the two or more transmitter WPT pads 902 and the two or more receiver WPT pads 904 is at least four times the gap 128 between the transmitter WPT pads 902 and the receiver WPT pads 904. By spreading the north and south poles of the WPT pads 902, 904 in relation to the length of the air gap 128, magnetic flux leakage may be reduced over designs where the distance 912 between poles is close to or smaller than the air gap 128.

Advantageously, having a magnetic flux path 906 through the WPT pads 902, 904 that runs through all WPT pads 902, 904 helps to reduce unequal power sharing between coils 202, 204 due to varying parameters, such as an unequal air gap 128, unequal coil lengths, component variations, and the like. Reducing unequal power sharing is beneficial so that a coil does not draw more power than another coil, which may cause unequal heating, unequal component stress, inefficiency, etc.

Where the apparatus 900 includes two transmitter WPT pads 902 and two receiver WPT pads 904, as depicted in Figures 9 and 10, in one embodiment the two receiver WPT pads 904 are positioned perpendicular to the two transmitter WPT pads 902. A perpendicular arrangement may be convenient for alignment of the WPT pads 902, 904, for reduction of magnetic flux leakage, and the like. Other designs may include other arrangements, for example in a diamond pattern.

Figure 11 is a top view of top and bottom WPT pads for a two pad, a four pad, a six pad and an eight pad configuration, all configured for magnetic flux sharing. For the two pad example, there is a top pad 1102 (i.e. a receiver WPT pad) and a bottom pad 1112 (i.e. a transmitter WPT pad) that are aligned. During charging, the top pad 1102 would be aligned over top of the bottom pad 1112.

In the four pad design, there are two top pads 1104 in parallel and two bottom pads 1114 positioned in parallel but perpendicular to the top pads 1104, as depicted in

Figures 9 and 10. In the 6 pad design, there are three top pads 1106 and three bottom pads 1116 where the top pads 1106 have two in parallel with a third pad positioned along a common edge of the two parallel pads. The bottom pads 1116 are in a similar layout with the third pad at an opposite end. In this arrangement, north and south poles of the three top pads 1106 and the three bottom pads 1116 may align. Spacing, coil layout and pad length may be chosen so that north and south poles align between the top and bottom pad 1106, 1116.

For the eight pad design, there are four top pads 1108 and four bottom pads 1118 where the top pads have two pads in parallel, a third pad at one end of the parallel pads and a fourth pad at the other end of the parallel pads. The bottom pads 1118 are arranged as shown in Figure 11 with two sets of parallel pads laid end-to-end. Again, spacing, coil layout and pad length may be chosen so that north and south poles align between the top and bottom pad 1108, 1118. In the layout, the top pad layout and the bottom pad layout may be reversed.

Layouts with multiple WPT pads are beneficial to increase power while maintaining a shared magnetic flux to help reduce unequal power sharing among coils of the WPT pads allowing a single power supply design to be repeated, thus allowing designs with increased power. The single power supply designs may be less dependent on electronic means to overcome power sharing. Note that various coil designs may also be used as well, such as designs with multiple coils in parallel, coils that are connected in series, and the like.

Figure 12A is a top view of a schematic block diagram of an apparatus 1200 with two top WPT pads 1204 and two bottom WPT pads 1202 where the top and bottom WPT pads 1202, 1204 have a ferrite structure that extends beyond where the WPT pads 1202, 1204 overlap. In one embodiment, each WPT pad 1202, 1204 has a single ferrite structure, such as the apparatus 301C of Figure 3D and the coils (e.g. 202, 204) may be arranged with a north pole and a south pole that are positioned in from the ends of the WPT pad 1202, 1204. The WPT pads 1202, 1204 are spaced so that portions of the ferrite structure extend beyond the WPT pad 1202, 1204 above or below, as depicted in Figure 12A. Where bi-plane WPT pads (e.g. 200A, 200B, 201, 203, 302A-C, 400) are used, each may have a main section 206 with two elongated side sections 1206. With this arrangement, the WPT pads 1202, 1204 are more tolerant of misalignment between the WPT pads 1202, 1204 because misalignment in any direction will still result in overlap of ferrite structures of the WPT pads 1202, 1204.

Figure 12B is a top view of a schematic block diagram of an apparatus with two top WPT pads 1204 and two bottom WPT pads 1202 where the top and bottom WPT pads 1202, 1204 have a ferrite structure that extends beyond where the WPT pads 1202, 1204 overlap and alignment of the top WPT pads 1204 are offset from the center. In the embodiment, when the top WPT pads 1204 are offset in two directions (i.e. X and Y where the Z-plane is vertical and would come out of the page), the elongated side sections 1206 of the ferrites structures of the WPT pads 1202, 1204 are long enough to allow for overlap with a significant amount of offset. The overlap allows for a higher degree of magnetic coupling than where the offset is such that the ferrite structures of the WPT pads 1202, 1204 to not fully overlap.

In one embodiment, an apparatus may include two or more WPT pads (e.g. similar to the WPT pads 200A, 200B, 201, 203, 301C, 302A, 302B, 303, 400 described above) with two or more charging coils (e.g. 202, 204) encircling a ferrite core (e.g. 206, 208, 210, 304) creating a north pole N and a south pole S for each WPT pad. For the apparatus, a charging coil (e.g. 202) of a first WPT pad of the two or more WPT pads is wired in series with a charging coil (e.g. 202) of a second WPT pad of the two or more WPT pads. In one embodiment, the charging coil of the first WPT pad wired in series is a first charging coil (e.g. 202) of the first WPT pad and the charging coil of the second WPT pad wired in series comprises a first charging coil (e.g. 204) of the second WPT pad and a second charging coil (e.g. 204) of the first WPT pad is wired in series with a second charging coil (e.g. 204) of the second WPT pad. Beneficially, wiring charging coils in series between WPT pads causes a more equal sharing of power between WPT pads where conditions of alignment are less than ideal. For example, if one transmitter WPT pad is closer to a corresponding receiver WPT pad than another transmitter WPT pad is to its corresponding receiver WPT pad, without total magnetic sharing, such as with the apparatus 900 of Figure 9, wired sharing due to charging coils wired in series causes a more equal sharing of power between coils than having all charging coils wired separately or connected in parallel.

In one embodiment, one charging coil (e.g. 202) of a first WPT pad 1302 is connected in series to one charging coil (e.g. 202) of a second WPT pad 1304. For example, one or more other charging coils of the WPT pads 1302, 1304 may not be connected in series. In another example, a WPT pad (e.g. 1302, 1304) may each have two charging coils 202, 204 and the first charging coils 202 of the WPT pads 1302, 1304

are wired in series and the second charging coils 204 of the WPT pads 1302, 1304 are also wired in series, for instance as depicted in Figure 13.

Figure 13 is a top view of one example of a WPT pad apparatus 1300 with charging coils 202, 204 of two WPT pads 1302, 1304 wired in series. The apparatus 1300 may include WPT pads 1302, 1304 that are similar to the WPT pads 200A, 200B, 201, 203, 301C, 302A, 302B, 303, 400 described above. The WPT pads 1302, 1304 may be transmitter pads 126 or receiver pads 128. Each WPT pad 1302, 1304 may include a first charging coil 202 and a second charging coil 204. The charging coils 202, 204 are connected in series in a way to generate magnetic flux without causing magnetic flux cancellation. For example, the first charging coils 202 of the first and second WPT pads 1302, 1304 may be wound to create a north pole N while the second charging coils 204 of the first and second WPT pads 1302, 1304 may be wound to create a south pole S. For example, the receiver WPT pads may be as depicted in the apparatus 1000 of Figure 10. In another embodiment, the first charging coil 202 of the first WPT pad 1302 may be wound to create a north pole N and in series with a first charging coil 202 of the second WPT pad 1304 wound to create a south pole S while the second charging coil 204 of the first WPT pad 1302 may be wound to create a south pole S and in series with a second charging coil 204 of the second WPT pad 1304 wound to create a north pole N where the receiver WPT pads are aligned as the apparatus 900 of Figures 9 and 10.

In one embodiment, transmitter WPT pads 126 have one or more charging coils 202, 204 connected in series while the receiver WPT pads 128 have charging coils that are not connected in series. In another embodiment, both the transmitter WPT pads 126 and the receiver WPT pads 128 have charging coils connected in series. In another embodiment, the receiver WPT pads 128 of a WPT apparatus have charging coils connected in series while the transmitter WPT pads 126 are not connected in series. Figure 14 illustrates this embodiment.

Figure 14 is a schematic diagram of an apparatus 1400 depicting side views of transmitter and receiver WPT pads 126, 128 where the receiver WPT pads 128 are wired in series and the transmitter WPT pads 126 each have a separate power supply module 1402. One of skill in the art will recognize that an actual implementation will have the transmitter and receiver WPT pads 126, 128 rotated and positioned and the depiction is merely to illustrate connection of the transmitter and receiver WPT pads 126, 128. The side views of the transmitter and receiver WPT pads 126, 128, in one embodiment, are similar to the apparatus 700 of Figure 7. Other embodiments may include an

arrangement such as the apparatus 900 of Figures 9 and 10 and the apparatus 1000 of Figure 10, which may be similar to the WPT pads 126, 128 of the apparatus 1400 of Figure 14. In other embodiments, the apparatus 1400 may include a single layer ferrite structure as depicted in Figure 3D. Other configurations for the WPT pads 126, 128 may also be used, such as circular WPT pads with the charging coils located on one side of an associated ferrite structure, such as depicted in Figure 3A.

In the embodiment, the charger coils 202, 204 of the receiver WPT pads 128 may be wired to one or more diode bridges 1404, which may then feed a load 1406. The diode bridges 1404 and load 1406 may be configured as depicted in the system 100 of Figure 1. In addition, while diode bridges 1404 and a load 1406 are depicted for simplicity in Figure 14, one of skill in the art will recognize that other elements may be included in the secondary circuit 130, which may include the diode bridges 1404. For example, the secondary circuit 130 may include a converter, control circuitry, a voltage regulator or other elements known to those of skill in the art.

In another embodiment, the transmitter WPT pads 126 are wired with charging coils 202, 204 in series and the charging coils 202, 204 of the receiver WPT pads 128 are not connected in series. In another embodiment, the transmitter WPT pads 126 are wired with charging coils 202, 204 in series and the charging coils 202, 204 of the receiver WPT pads 128 are also connected in series as depicted. In one embodiment, where charging coils 202, 204 are connected in series, each charging coil of a first and a second WPT pad 1302, 1304 may include two or more conductors and each conductor of the charging coil of the first WPT pad is wired in series with a corresponding conductor of the charging coil of the second WPT pad. For example, the charging coils 202, 204 may be configured as the apparatus 203 of Figure 2D, except that the two charging coils 202, 204 of a WPT pad are not connected as depicted in Figure 2D, but are instead wired to charging coils of another WPT pad. Charging coils wound in parallel, as depicted in Figure 2D may be beneficial for series wiring of charging coils in order to increase power capabilities of charging coils.

While an embodiment with two transmitter WPT pads 126 and two receiver WPT pads 128 is depicted in Figure 14, other configurations with one transmitter WPT pad 126 and one receiver WPT pad 128 and with three or more transmitter WPT pads 126 and three or more receiver pads 128 where some or all of the charging coils (e.g. 202, 204) are wired in series. In some embodiments where charging coils are wired in series as depicted in Figure 13, the WPT pads (e.g. 1302, 1304) may be bi-plane WPT pads (e.g.

200A, 200B, 201, 203, 302A, 302B, 303, 400) as depicted in Figures 2A-2D, 3D-3G, and 4, or may include a single layer ferrite structure as depicted in Figure 3D.

In some embodiments, both magnetic flux sharing and series connected coils are used for increasing equal power sharing within a WPT apparatus. For example, where transmitter WPT pads 126 and receiver WPT pads 128 are arranged as depicted in the apparatus 1000 of Figure 10, connecting charging coils across either or both of the transmitter and receiver WPT pads 1002, 1004 may provide both magnetic flux sharing and sharing due to series connected charging coils 202, 204. For example, where either or both of the transmitter and receiver WPT pads 1002, 1004 of the apparatus 1000 of Figure 10 are wired as depicted in Figure 13, the magnetic coupling shown in Figure 10 is matched with the series wiring as shown in Figure 13. As a result, magnetic flux sharing will help equalize power between two charging coils 202, 204 of a particular WPT pad (e.g. 1002 or 1004) while the series wiring as depicted in Figure 13 will help equalize power sharing between the two adjacent sets of WPT pads 1002, 1004. As a result, configurations similar to what is depicted in Figure 10 may provide a measure of equalization of power between the various charging coils 202, 204.

As with magnetic flux sharing, the WPT pads (e.g. 1002, 1004, 1302, 1304, 126, 128) may be configured with a particular distance between north poles N and south poles S and may also be spaced a distance apart so that the spacing and/or distance between poles is larger than a gap 108 between transmitter WPT pads 126 and receiver WPT pads 128. Spacing the WPT pads apart and having the WPT pads with north and south poles N, S spaced a certain distance apart with regard to a gap 108 between transmitter and receiver WPT pads 126, 128 increases magnetic flux sharing as designed with less leakage magnetic flux.

The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

CLAIMS

1. An apparatus comprising:
 - a first charging coil comprising one or more conductors arranged in a first winding pattern;
 - 5 a second charging coil comprising one or more conductors arranged in a second winding pattern; and
 - a ferrite structure comprising a main section with a top side, a first side section and a second side section, the first side section and the second side section each comprising a bottom side,
 - 10 wherein a portion of the top side of the main section is adjacent to a portion of the bottom side of the first side section and the second side section, and
 - wherein a portion of the first charging coil and a portion of the second charging coil are positioned adjacent to the top side of the main section interior to where the first side section and the second side section are adjacent to the top side of the main section, a portion of the first charging coil is adjacent to the bottom side of the first side section and a portion of the second charging coil is adjacent to the bottom side of the second side section.
2. The apparatus of claim 1, wherein the main section is magnetically coupled to the first side section and to the second side section.
- 20 3. The apparatus of claim 1, further comprising a space between the portion of the first charging coil and the portion of the second charging coil located adjacent to the top side of the main section.
4. The apparatus of claim 1, wherein the main section, the first side section and the second side section of the ferrite structure are separate and wherein the top side of the main section is in contact with the bottom side of the first side section and with the bottom side of the second side section.
- 25 5. The apparatus of claim 1, wherein the portion of the first charging coil and the portion of the second charging coil adjacent to the top side of the main section are wound in a spiral pattern in a plane parallel to the top side of the main section.
- 30 6. The apparatus of claim 1, wherein the ferrite structure comprises a first edge and a second edge, the first and second edge located distal to a plane bisecting the main section, the first side section and the second side section, the first charging coil and the second charging coil extend past the first and second edges of the ferrite structure.

7. The apparatus of claim 1, wherein the ferrite structure further comprises a plurality of notches, each notch accommodating a portion of one of the first charging coil and the second charging coil during a transition between the main section and one of the first side section and the second side section.
- 5 8. The apparatus of claim 1, wherein the main section is joined to the first side section and the second side section.
9. The apparatus of claim 1, wherein the portion of the first charging coil adjacent to the bottom side of the first side section is wound to group the one or more conductors in a pattern that minimizes one or more of conductor length and distance from a center point
10 of the main section between the first charging coil and the second charging coil.
10. The apparatus of claim 1, wherein the one or more conductors of the first charging coil and the one or more conductors of the second charging coil each comprise two coils wound in a parallel pattern wherein a first coil of a charging coil of the first or second charging coils is wound adjacent to a second coil of the charging coil.
- 15 11. The apparatus of claim 1, wherein each of the one or more conductors of the first charging coil and the second charging coil are stacked in layers over the main section, each layer is in a plane parallel to the top side of the main section.
12. The apparatus of claim 1, wherein the first and second charging coils and the ferrite structure comprise a first pad section and further comprising a second pad section, the
20 second pad section comprising two or more additional charging coils and an additional ferrite structure arranged the same as the first pad section, wherein the first pad section and the second pad section are arranged to form a charging pad.
13. The apparatus of claim 1, wherein the apparatus is part of a primary pad of a wireless power transfer system and further comprising an inverter connected to the first and
25 second charging coils, the inverter injecting a signal in the first and second charging coils, wherein the injected signal generates an electromagnetic field radiating in a direction away from the top side of the main section.
14. The apparatus of claim 13, further comprising a secondary pad magnetically coupled to the primary pad, the secondary pad converting energy from the electromagnetic field into
30 electrical energy, and further comprising a secondary circuit connected to the secondary pad, wherein the secondary circuit receives the electrical energy from the secondary pad and conditions the electrical energy for use by a load.

15. An apparatus comprising:

a first charging coil comprising one or more conductors arranged in a first winding pattern;

a second charging coil comprising one or more conductors arranged in a second winding pattern; and

a ferrite structure comprising a main section with a top side, a first side section and a second side section, the first side section and the second side section each comprising a bottom side, the main section magnetically coupled to the first side section and to the second side section,

wherein the ferrite structure is multi-level and the bottom side of the main section is offset from the bottom side of the first side section and from the second side section, and

wherein a portion of the first charging coil and a portion of the second charging coil are positioned adjacent to the top side of the main section interior to where the first side section and the second side section are adjacent to the top side of the main section, a portion of the first charging coil is adjacent to the bottom side of the first side section and a portion of the second charging coil is adjacent to the bottom side of the second side section.

16. The apparatus of claim 15, wherein the offset is at least a thickness of one or more of the first charging coil and the second charging coil, the thickness measured in a direction perpendicular to the bottom side of one or more of the first side section and the second side section.

17. The apparatus of claim 15, wherein the portion of the first charging coil and the portion of the second charging coil adjacent to the top side of the main section are wound in a spiral pattern in a plane parallel to the top side of the main section.

18. The apparatus of claim 15, wherein the ferrite structure comprises a first edge and a second edge, the first and second edges located distal to a plane bisecting the main section, the first side section and the second side section, the first charging coil and the second charging coil extend past the first and second edges of the ferrite structure.

19. A system for wireless power transfer, the system comprising:

a first charging coil comprising one or more conductors arranged in a first winding pattern;

a second charging coil comprising one or more conductors arranged in a second winding pattern;

a ferrite structure comprising a main section with a top side, a first side section and a second side section, the first side section and the second side section each comprising a bottom side,

wherein a portion of the top side of the main section is adjacent to a portion of the bottom side of the first side section and the second side section, and

wherein a portion of the first charging coil and a portion of the second charging coil are positioned adjacent to the top side of the main section interior to where the first side section and the second side section are adjacent to the top side of the main section, a portion of the first charging coil is adjacent to the bottom side of the first side section and a portion of the second charging coil is adjacent to the bottom side of the second side section; and

an inverter connected to the first and second charging coils, the inverter injecting a signal in the first and second charging coils, wherein the injected signal generates an electromagnetic field radiating in a direction away from the top side of the main section.

20. The system of claim 19, wherein the first charging coil, the second charging coil and the ferrite structure comprise a primary pad and further comprising a secondary pad magnetically coupled to the primary pad, the secondary pad converting energy from the electromagnetic field into electrical energy, and further comprising a secondary circuit connected to the secondary pad, wherein the secondary circuit receives the electrical energy from the secondary pad and conditions the electrical energy for use by a load.

21. An apparatus comprising:

one or more transmitter wireless power transmission ("WPT") pads, each comprising one or more coils encircling a ferrite core creating a north pole and a south pole for each WPT pad; and

one or more receiver WPT pads, each comprising one or more coils encircling a ferrite core creating a north pole and a south pole for each WPT pad,

wherein the one or more transmitter WPT pads and the one or more receiver WPT pads are arranged so that when the one or more receiver WPT pads are aligned over the one or more transmitter WPT pads, each north pole of a transmitter WPT pad is aligned under a south pole of a receiver WPT pad and each south pole of a transmitter WPT pad is aligned under a north pole of a receiver WPT pad.

22. The apparatus of claim 21, wherein each north pole of a transmitter WPT pad is paired with a single south pole of a receiver WPT pad and each south pole of a transmitter WPT pad is paired with a single north pole of a receiver WPT pad.
23. The apparatus of claim 21, wherein the one or more transmitter WPT pads comprise two or more transmitter WPT pads and the one or more receiver WPT pads comprise two or more receiver WPT pads and further comprising a gap between each of the two or more transmitter WPT pads and a gap between each of the two or more receiver WPT pads.
24. The apparatus of claim 23, wherein the gap between the two or more transmitter WPT pads and the gap between the two or more receiver WPT pads is larger than a gap between the transmitter WPT pads and the receiver WPT pads.
25. The apparatus of claim 24, wherein the gap between the two or more transmitter WPT pads and the gap between the two or more receiver WPT pads is at least four times larger than the gap between the transmitter WPT pads and the receiver WPT pads.
26. The apparatus of claim 21, wherein the one or more transmitter WPT pads comprise two or more transmitter WPT pads and the one or more receiver WPT pads comprise two or more receiver WPT pads and further comprising a distance between the north and south poles of a WPT pad of the two or more transmitter WPT pads and the two or more receiver WPT pads, the distance greater than a gap between the transmitter WPT pads and the receiver WPT pads.
27. The apparatus of claim 26, wherein the distance between the north and south poles of a WPT pad of the two or more transmitter WPT pads and the two or more receiver WPT pads is at least four times the gap between the transmitter WPT pads and the receiver WPT pads.
28. The apparatus of claim 21, wherein the one or more transmitter WPT pads comprise two transmitter WPT pads and the one or more receiver WPT pads comprise two receiver WPT pads and the two receiver WPT pads are positioned perpendicular to the two transmitter WPT pads.
29. The apparatus of claim 21, wherein the one or more transmitter WPT pads comprise three transmitter WPT pads and the one or more receiver WPT pads comprise three receiver WPT pads and the three receiver WPT pads are positioned with a first and a second transmitter WPT pads positioned in parallel and a third transmitter WPT pad positioned perpendicular to the first and second transmitter WPT pads and located adjacent to an end of the first and second transmitter WPT pads and wherein the three receiver WPT pads

are arranged the same as the three transmitter WPT pads and are oriented 180 degrees from the position of the three transmitter WPT pads during wireless power transfer.

30. The apparatus of claim 21, wherein the one or more transmitter WPT pads comprise four transmitter WPT pads and the one or more receiver WPT pads comprise four receiver WPT pads and the four transmitter WPT pads are arranged with a first and a second transmitter WPT pads arranged in parallel and a third and a fourth transmitter WPT pads arranged in parallel with the first and second transmitter WPT pads positioned end to end with the third and fourth transmitter WPT pads and the four receiver WPT pads are arranged with a first and a second receiver WPT pads in parallel with a third and a fourth receiver WPT pads arranged perpendicular to the first and second receiver WPT pads wherein the third receiver WPT pad is located at a first end of the first and second receiver WPT pads and the fourth receiver WPT pad is located at a second end of the first and second receiver WPT pads, the first end distal to the second end.

31. The apparatus of claim 21, wherein each of the one or more transmitter WPT pads and each of the one or more receiver WPT pads comprise:

a first charging coil comprising one or more conductors arranged in a first winding pattern; and

a second charging coil comprising one or more conductors arranged in a second winding pattern, and

wherein a portion of the first charging coil and a portion of the second coil are positioned adjacent to a top side and a bottom side of the ferrite structure.

32. The apparatus of claim 31, wherein the ferrite structure comprises a split ferrite structure comprising a main section with a top side, a first side section and a second side section, the first side section and the second side section each comprising a bottom side and wherein a portion of the top side of the main section is adjacent to a portion of the bottom side of the first side section and the second side section, and wherein a portion of the first charging coil and a portion of the second coil are positioned adjacent to the top side of the main section interior to where the first side section and the second side section are adjacent to the top side of the main section, a portion of the first charging coil is adjacent to the bottom surface of the first side section and a portion of the second charging coil is adjacent to the bottom surface of the second side section.

33. The apparatus of claim 32, wherein the one or more transmitter WPT pads and the one or more receiver WPT pads are oriented during charging wherein the first side section and

the second side section of each WPT pad are closer than the main section of each WPT pad.

34. The apparatus of claim 32, further comprising a gap between the portion of the first charging coil and the portion of the second charging coil located adjacent to the top of the main section.

35. The apparatus of claim 31, wherein the main section is magnetically coupled to the first side section and to the second side section.

36. The apparatus of claim 31, wherein the portion of the first charging coil and the portion of the second charging coil adjacent to the top surface of the main section are wound in a spiral pattern in a plane parallel to the top surface of the main section.

37. The apparatus of claim 31, wherein the one or more conductors of the first charging coil and the one or more conductors of the second charging coil each comprise two coils wound in a parallel pattern wherein a first coil of a charging coil of the first or second charging coils is wound adjacent to a second coil of the charging coil.

38. An apparatus comprising:

two or more transmitter wireless power transmission ("WPT") pads, each transmission WPT pad comprising one or more coils encircling a ferrite core creating a north pole and a south pole for each WPT pad; and

two or more receiver WPT pads, each receiver WPT pad comprising one or more coils encircling a ferrite core creating a north pole and a south pole for each WPT pad, and further comprising a gap between each of the two or more transmitter WPT pads and a gap between each of the two or more receiver WPT pads,

wherein the gap between the two or more transmitter WPT pads and the gap between the two or more receiver WPT pads is larger than a gap between the transmitter WPT pads and the receiver WPT pads, and further comprising a distance between the north and south poles of a WPT pad of the two or more transmitter WPT pads and the two or more receiver WPT pads, the distance greater than a gap between the transmitter WPT pads and the receiver WPT pads,

wherein the two receiver WPT pads are positioned perpendicular to the two transmitter WPT pads, and

wherein the two or more transmitter WPT pads and the two or more receiver WPT pads are arranged so that when the two or more receiver WPT pads are

aligned over the two or more transmitter WPT pads, each north pole of a transmitter WPT pad is aligned under a south pole of a receiver WPT pad and each south pole of a transmitter WPT pad is aligned under a north pole of a receiver WPT pad.

5 39. The apparatus of claim 38, wherein each of the two or more transmitter WPT pads and each of the two or more receiver WPT pads comprise:

a first charging coil comprising one or more conductors arranged in a first winding pattern; and

10 a second charging coil comprising one or more conductors arranged in a second winding pattern, and

wherein a portion of the first charging coil and a portion of the second coil are positioned adjacent to a top side and a bottom side of the ferrite structure,

15 wherein the ferrite structure comprises a split ferrite structure comprising a main section with a top side, a first side section and a second side section, the first side section and the second side section each comprising a bottom side and wherein a portion of the top side of the main section is adjacent to a portion of the bottom side of the first side section and the second side section, and wherein a portion of the first charging coil and a portion of the second coil are positioned adjacent to the top side of the main section
20 interior to where the first side section and the second side section are adjacent to the top side of the main section, a portion of the first charging coil is adjacent to the bottom surface of the first side section and a portion of the second charging coil is adjacent to the bottom surface of the second side section.

25 40. A system comprising:

one or more transmitter wireless power transmission (“WPT”) pads, each comprising one or more coils encircling a ferrite core creating a north pole and a south pole for each WPT pad;

30 one or more receiver WPT pads, each comprising one or more coils encircling a ferrite core creating a north pole and a south pole for each WPT pad,

wherein the one or more transmitter WPT pads and the one or more receiver WPT pads are arranged so that when the one or more receiver WPT pads are aligned over the one or more transmitter WPT pads, each north pole of a transmitter WPT pad is aligned under a south pole of a receiver WPT pad

and each south pole of a transmitter WPT pad is aligned under a north pole of a receiver WPT pad; and

an inverter connected to the one or more charging coils of the transmission WPT pads, the inverter injecting a signal in the one or more charging coils, wherein the injected signal generates an electromagnetic field radiating in a direction away from a top side of the transmission WPT pads.

41. An apparatus comprising:

two or more wireless power transmission (“WPT”) pads, each WPT pad comprising two or more charging coils encircling a ferrite core creating a north pole and a south pole for each WPT pad,

wherein a charging coil of a first WPT pad of the two or more WPT pads is wired in series with a charging coil of a second WPT pad of the two or more WPT pads.

42. The apparatus of claim 41, wherein the charging coil of the first WPT pad wired in series comprises a first charging coil of the first WPT pad and the charging coil of the second WPT pad wired in series comprises a first charging coil of the second WPT pad and wherein a second charging coil of the first WPT pad is wired in series with a second charging coil of the second WPT pad.

43. The apparatus of claim 41, wherein the two or more WPT pads comprise transmitter WPT pads and further comprising two or more receiver WPT pads wherein a charging coil of a first receiver WPT pad of the two or more receiver WPT pads is wired in series with a charging coil of a second receiver WPT pad of the two or more receiver WPT pads.

44. The apparatus of claim 43, wherein the charging coil of the first receiver WPT pad wired in series comprises a first charging coil of the first receiver WPT pad and the charging coil of the second receiver WPT pad wired in series comprises a first charging coil of the second receiver WPT pad and wherein a second charging coil of the first receiver WPT pad is wired in series with a second charging coil of the second receiver WPT pad, and wherein the charging coil of the first transmitter WPT pad wired in series comprises a first charging coil of the first transmitter WPT pad and the charging coil of the second transmitter WPT pad wired in series comprises a first charging coil of the second transmitter WPT pad and wherein a second charging coil of the first transmitter WPT pad is wired in series with a second charging coil of the second transmitter WPT pad.

45. The apparatus of claim 41, wherein the two or more WPT pads comprise transmitter WPT pads and further comprising two or more receiver WPT pads arranged so that when the two or more receiver WPT pads are aligned over the two or more transmitter WPT pads, each north pole of a transmitter WPT pad is aligned under a south pole of a receiver WPT pad and each south pole of a transmitter WPT pad is aligned under a north pole of a receiver WPT pad.
46. The apparatus of claim 45, wherein each receiver WPT pad of the two or more receiver WPT pads is oriented to align with one transmitter WPT pad of the two or more transmitter WPT pads in a same orientation as the one transmitter WPT pad.
47. The apparatus of claim 46, wherein each receiver WPT pad of the two or more receiver WPT pads comprises a north pole and a south pole and the receiver WPT pad is oriented with the north pole to align with a south pole of a transmitter WPT pad of the two or more transmitter WPT pads and the south pole of the receiver WPT pad is oriented to align with a separate transmitter WPT pad of the two or more transmitter WPT pads.
48. The apparatus of claim 41, wherein the two or more WPT pads comprise two or more receiver WPT pads and further comprising two or more transmitter WPT pads, wherein each charging coil of the transmitter WPT pads are wired to a separate power supply module and the charging coils of the receiver WPT pads wired in series are connected to a load.
49. The apparatus of claim 48, wherein when the receiver WPT pads are aligned with the transmitter WPT pads, one receiver WPT pad of the two or more receiver WPT pads is aligned with one transmitter WPT pad of the two or more transmitter WPT pads, wherein the north pole of an aligned WPT pad aligns with the south pole of an aligned WPT pad.
50. The apparatus of claim 41, wherein the two or more WPT pads comprise two or more transmitter WPT pads and further comprising two or more receiver WPT pads, wherein each charging coil of the receiver WPT pads are wired to a load and the charging coils of the receiver WPT pads wired in series are connected to a power supply module.
51. The apparatus of claim 50, wherein when the receiver WPT pads are aligned with the transmitter WPT pads, one receiver WPT pad of the two or more receiver WPT pads is aligned with one transmitter WPT pad of the two or more transmitter WPT pads, wherein the north pole of an aligned WPT pad aligns with the south pole of an aligned WPT pad.
52. The apparatus of claim 41, wherein the charging coil of the first WPT pad and the charging coil of the second WPT pad wired in series each comprise two or more

conductors, wherein each conductor of the charging coil of the first WPT pad is wired in series with a corresponding conductor of the charging coil of the second WPT pad.

53. The apparatus of claim 41, further comprising a gap between each of the two or more WPT pads.

5 54. The apparatus of claim 53, wherein the two or more WPT pads comprise two or more transmitter WPT pads and further comprising two or more receiver WPT pads and wherein the gap between the two or more transmitter WPT pads and the gap between the two or more receiver WPT pads is each larger than a gap between the transmitter WPT pads and the receiver WPT pads.

10 55. The apparatus of claim 41, wherein the two or more WPT pads comprise two or more transmitter WPT pads and further comprising two or more receiver WPT pads and further comprising a distance between the north and south poles of a WPT pad of the two or more transmitter WPT pads and the two or more receiver WPT pads, the distance greater than a gap between the transmitter WPT pads and the receiver WPT pads.

15 56. The apparatus of claim 41, wherein the charging coils of each of the two or more WPT pads comprise:

a first charging coil comprising one or more conductors arranged in a first winding pattern; and

20 a second charging coil comprising one or more conductors arranged in a second winding pattern, and

wherein a portion of the first charging coil and a portion of the second charging coil are positioned adjacent to a top side and a bottom side of the ferrite structure.

25 57. The apparatus of claim 56, wherein the ferrite structure comprises a split ferrite structure comprising a main section with a top side, a first side section and a second side section, the first side section and the second side section each comprising a bottom side and wherein a portion of the top side of the main section is adjacent to a portion of the bottom side of the first side section and the second side section, and wherein a portion of the first charging coil and a portion of the second coil are positioned adjacent to the top side of the main section interior to where the first side section and the second side section are adjacent to the top side of the main section, a portion of the first charging coil is adjacent to the bottom surface of the first side section and a portion of the second charging coil is adjacent to the bottom surface of the second side section.

30

58. The apparatus of claim 56, wherein the portion of the first charging coil and the portion of the second charging coil adjacent to the top surface of the main section are wound in a spiral pattern in a plane parallel to the top surface of the main section.
59. An apparatus comprising:
- 5 two or more wireless power transmission (“WPT”) pads, each WPT pad comprising two or more charging coils encircling a ferrite core creating a north pole and a south pole for each WPT pad;
- wherein a first charging coil of a first WPT pad of the two or more WPT pads is wired in series with a first charging coil of a second WPT pad of the two
- 10 or more WPT pads; and
- wherein a second charging coil of the first WPT pad is wired in series with a second charging coil of the second WPT pad.
60. A system comprising:
- 15 two or more transmitter wireless power transmission (“WPT”) pads, each transmitter WPT pad comprising two or more charging coils encircling a ferrite core creating a north pole and a south pole for each transmitter WPT pad;
- wherein a first charging coil of a first transmitter WPT pad of the two or more transmitter WPT pads is wired in series with a first charging coil of a
- 20 second transmitter WPT pad of the two or more transmitter WPT pads, and wherein a second charging coil of the first transmitter WPT pad is wired in series with a second charging coil of the second transmitter WPT pad;
- two or more receiver WPT pads, each receiver WPT pad comprising two or more
- 25 charging coils encircling a ferrite core creating a north pole and a south pole for each receiver WPT pad;
- wherein a first charging coil of a first receiver WPT pad of the two or more receiver WPT pads is wired in series with a first charging coil of a second receiver WPT pad of the two or more receiver WPT pads, and wherein a
- 30 second charging coil of the first receiver WPT pad is wired in series with a second charging coil of the second receiver WPT pad;
- one or more inverters connected to the two or more charging coils of the transmission WPT pads, the inverter injecting a signal in the two or more charging coils, wherein the injected signal generates an electromagnetic

field radiating in a direction away from a top side of the transmission WPT pads.

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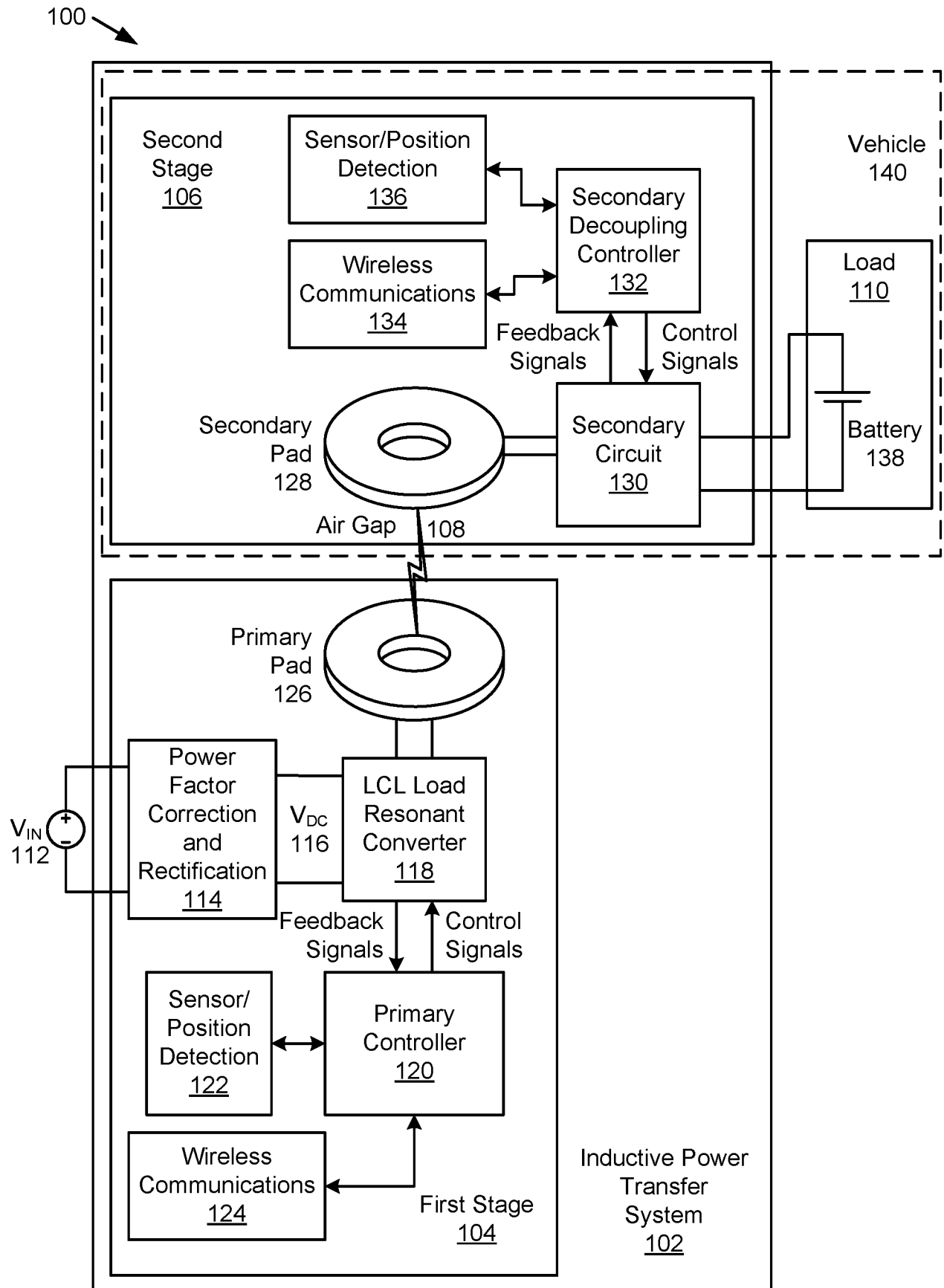
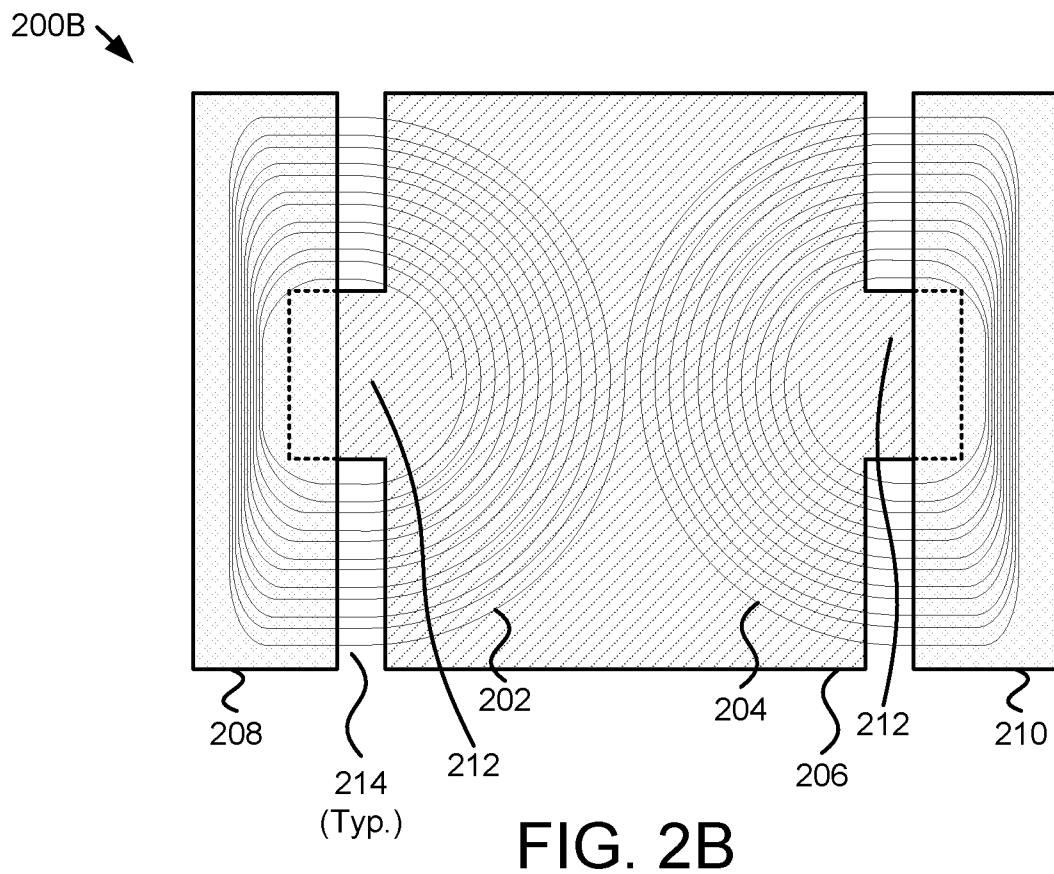
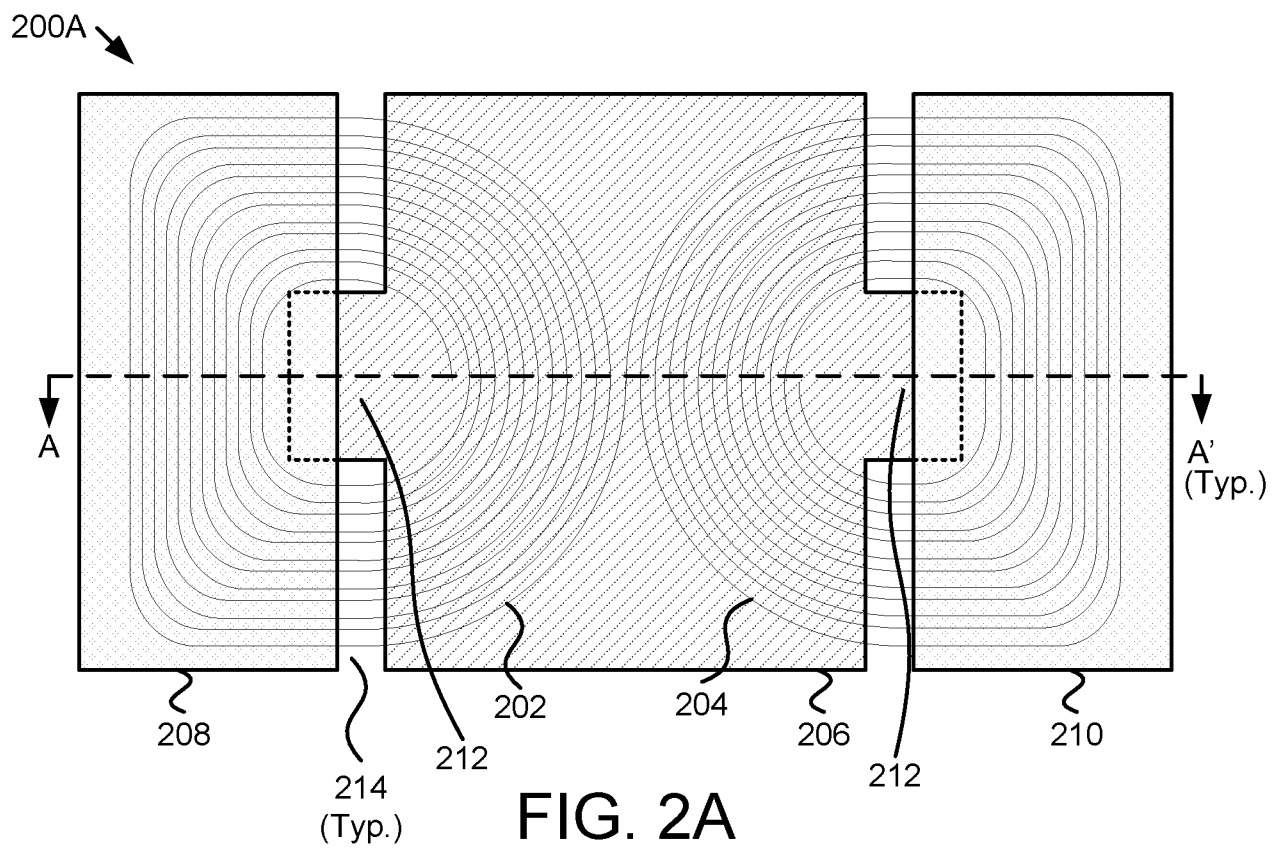


FIG. 1



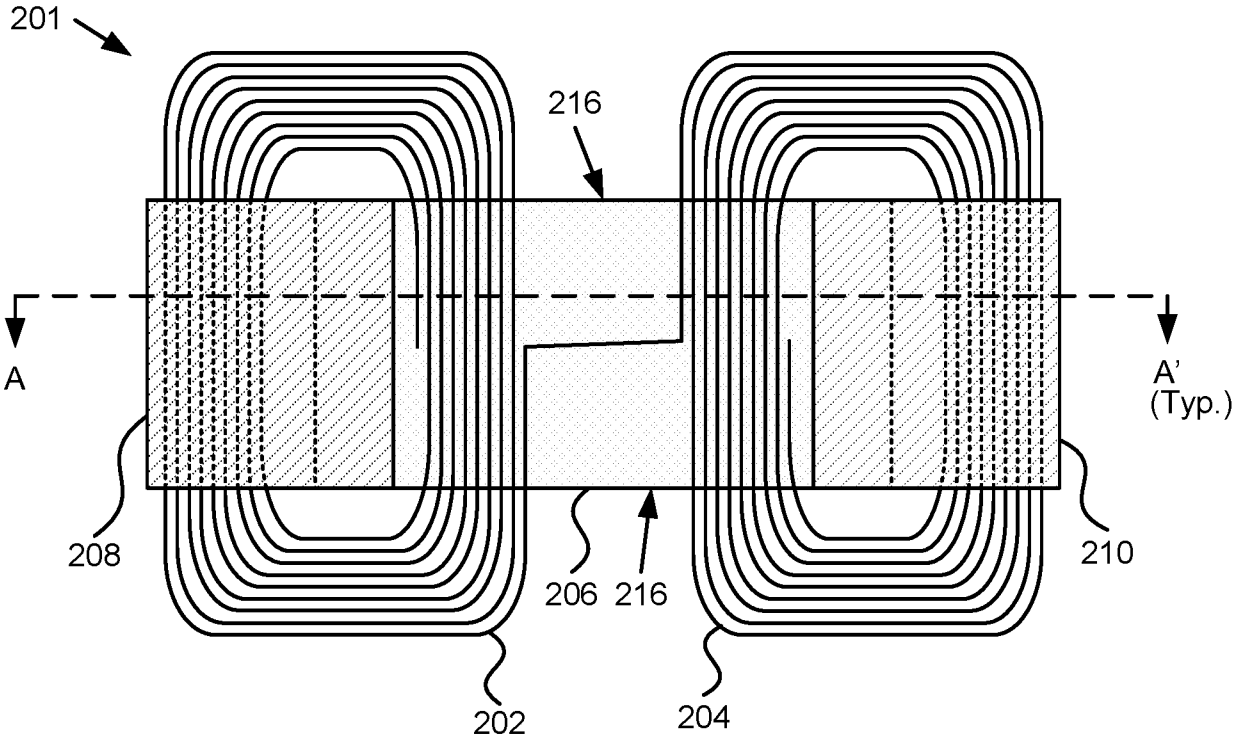


FIG. 2C

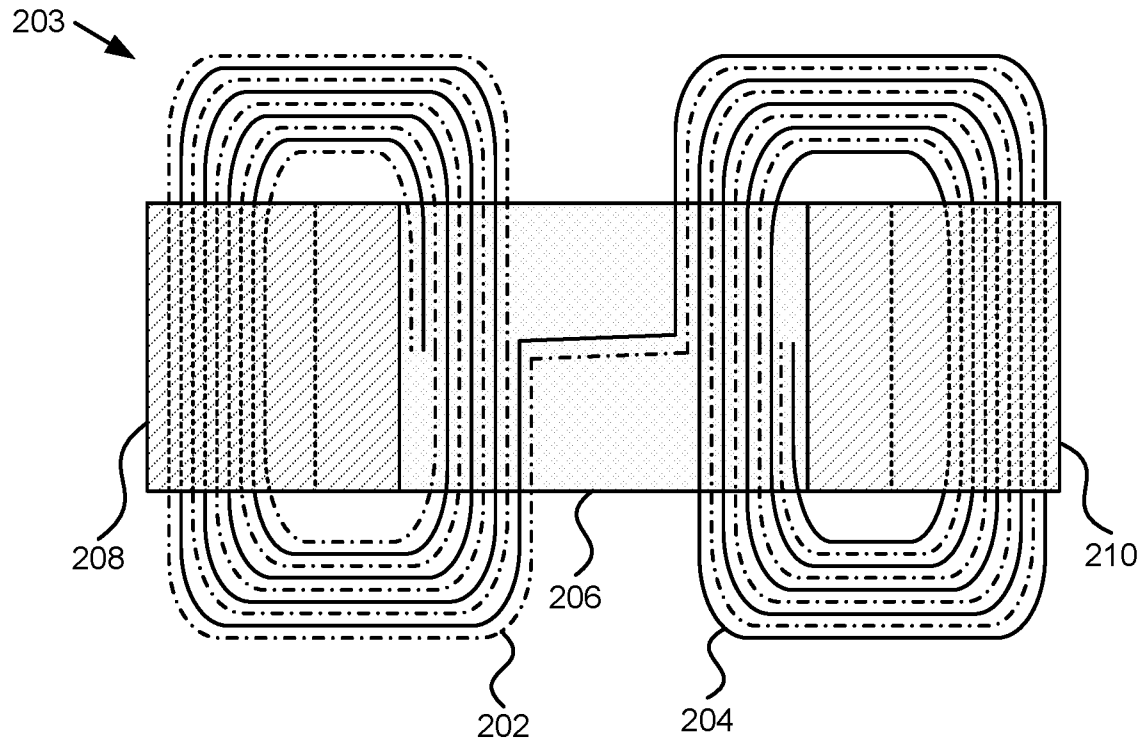


FIG. 2D

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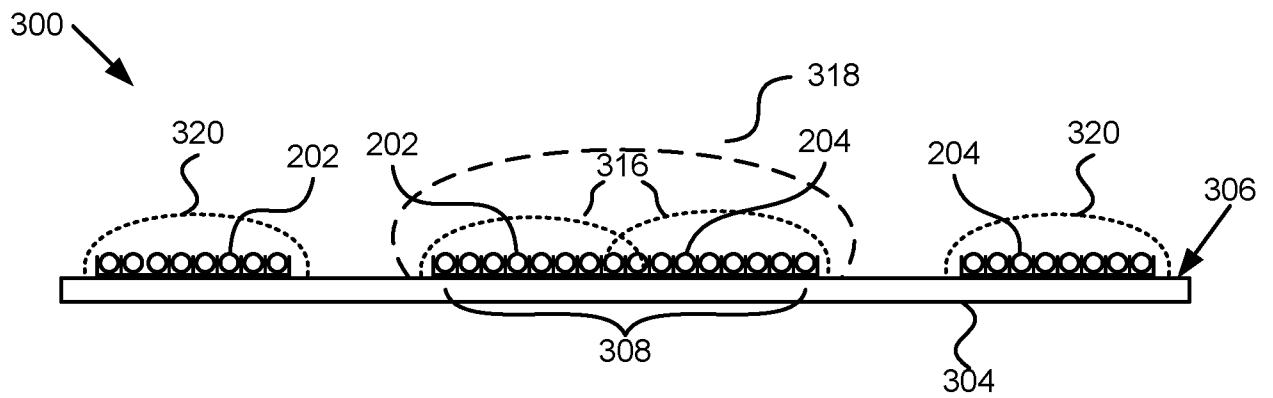


FIG. 3A

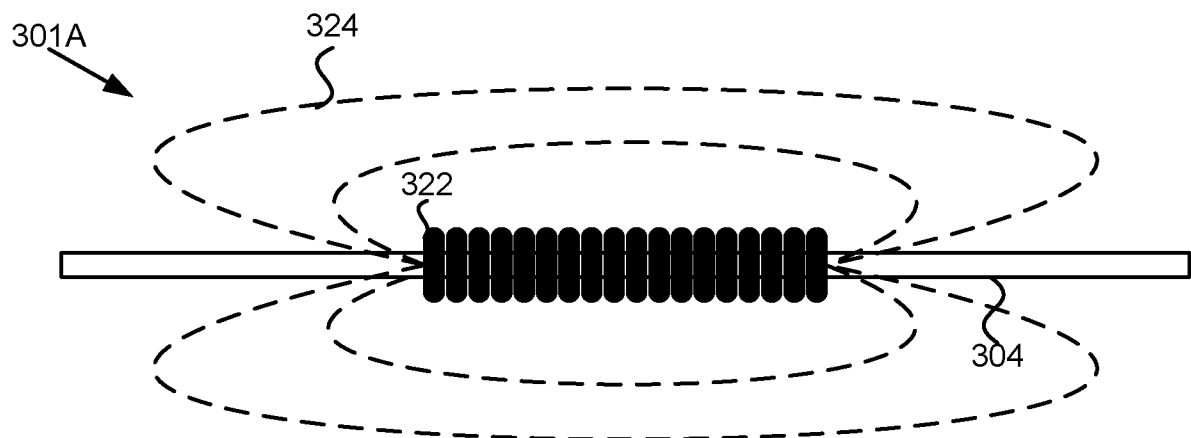


FIG. 3B

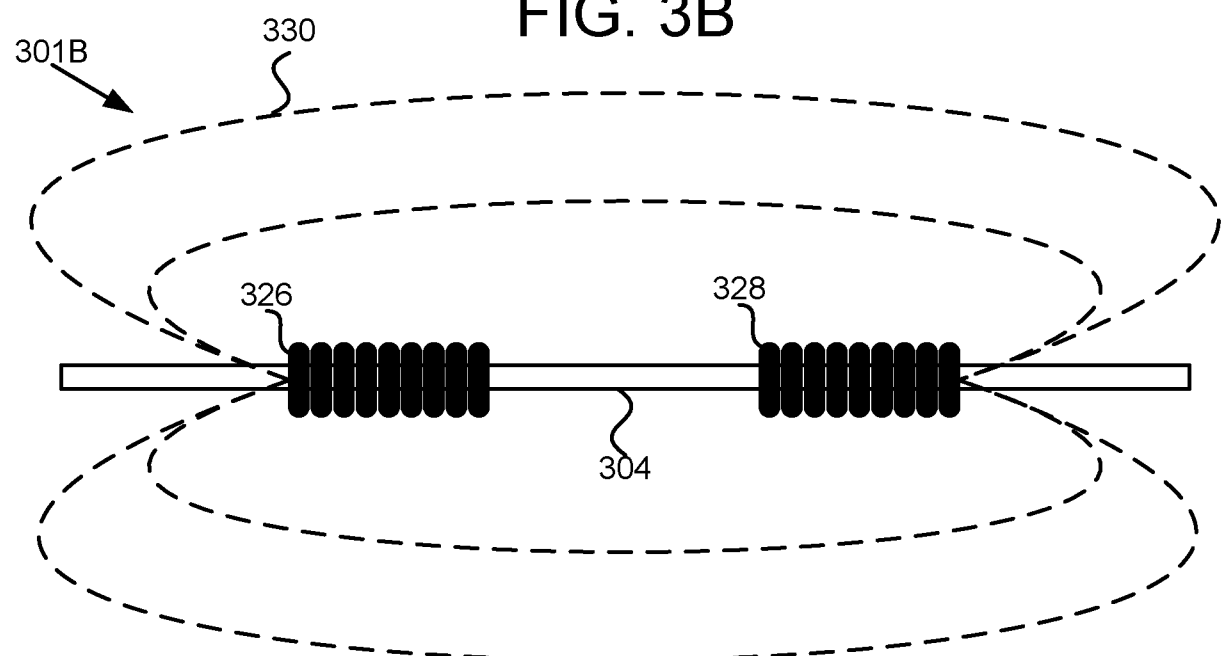


FIG. 3C

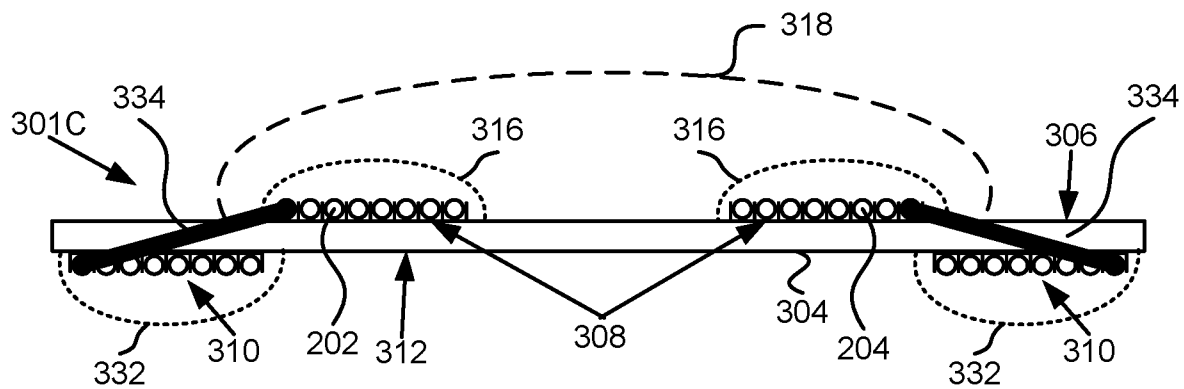


FIG. 3D

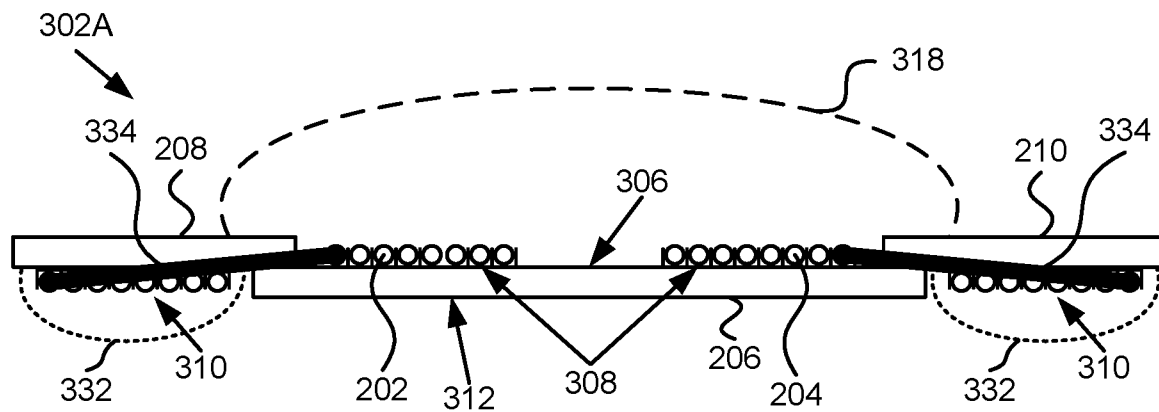


FIG. 3E

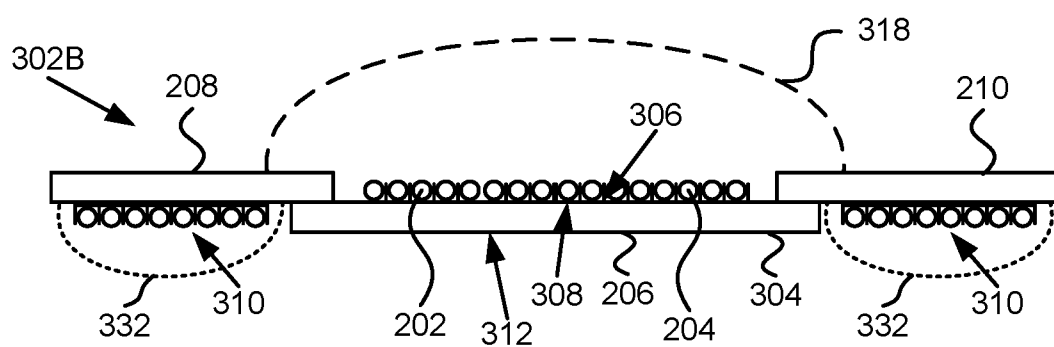


FIG. 3F

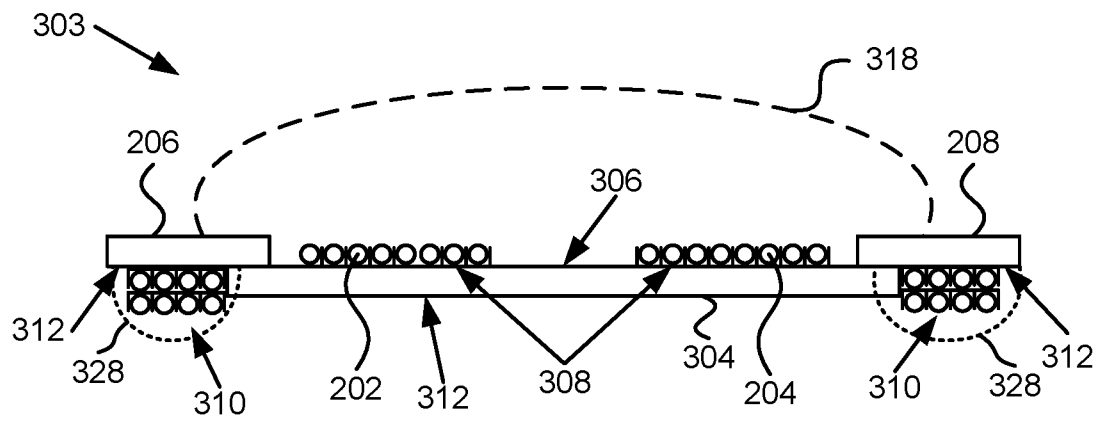


FIG. 3G

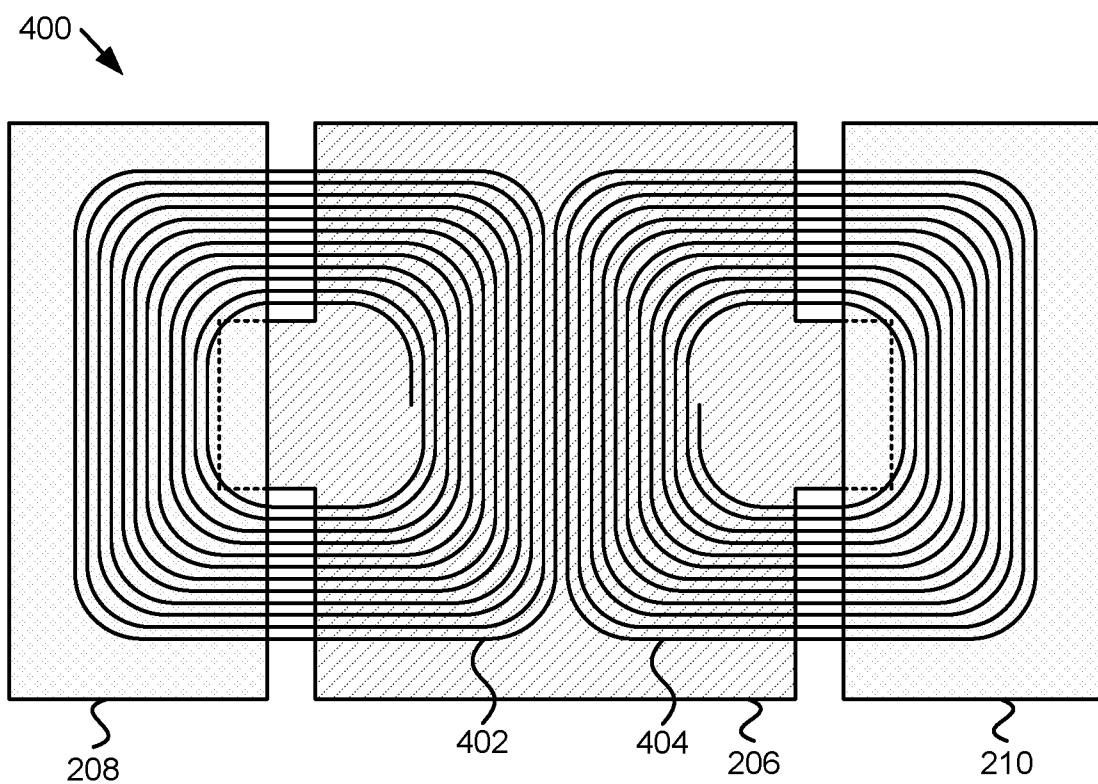


FIG. 4

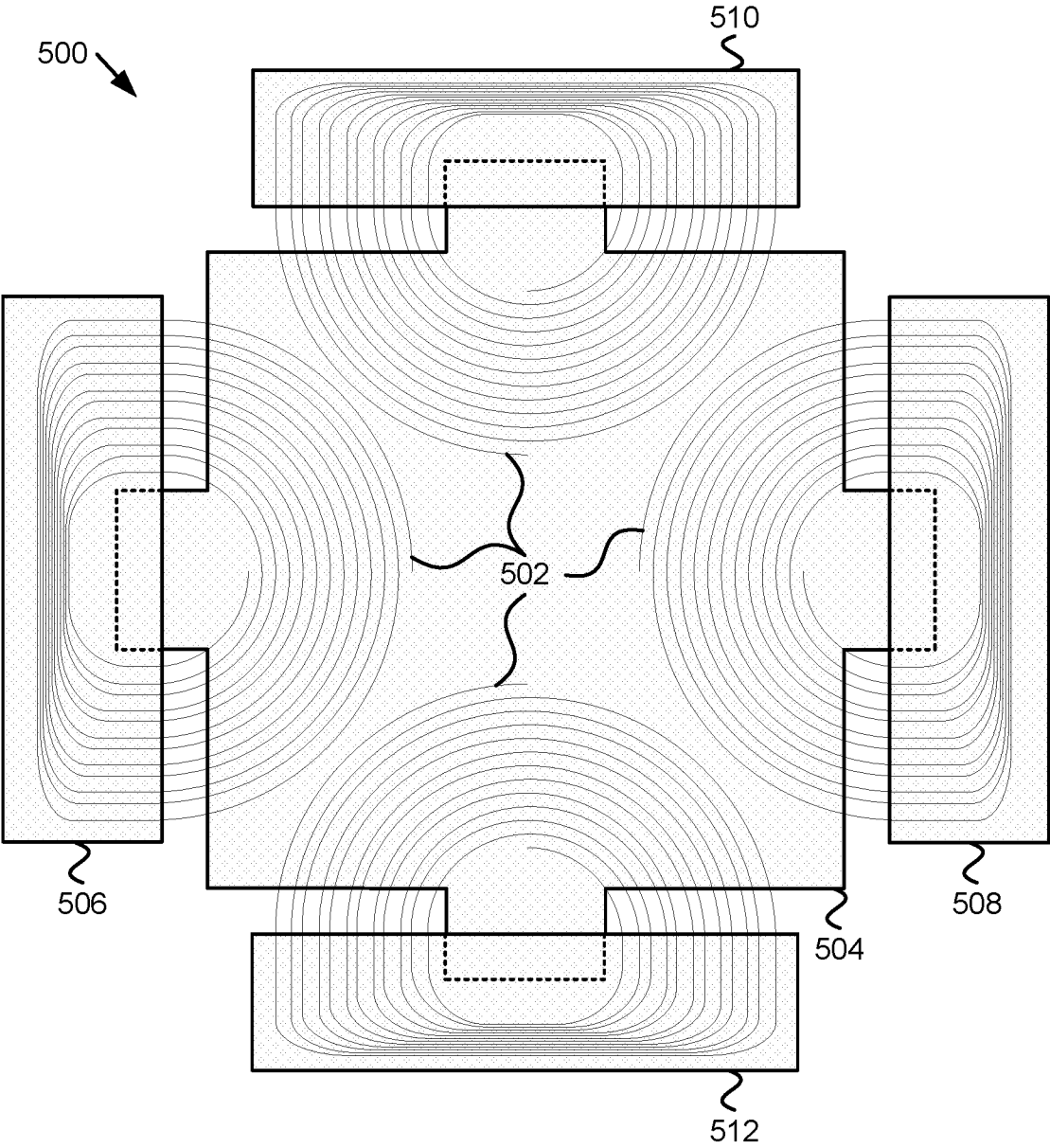


FIG. 5

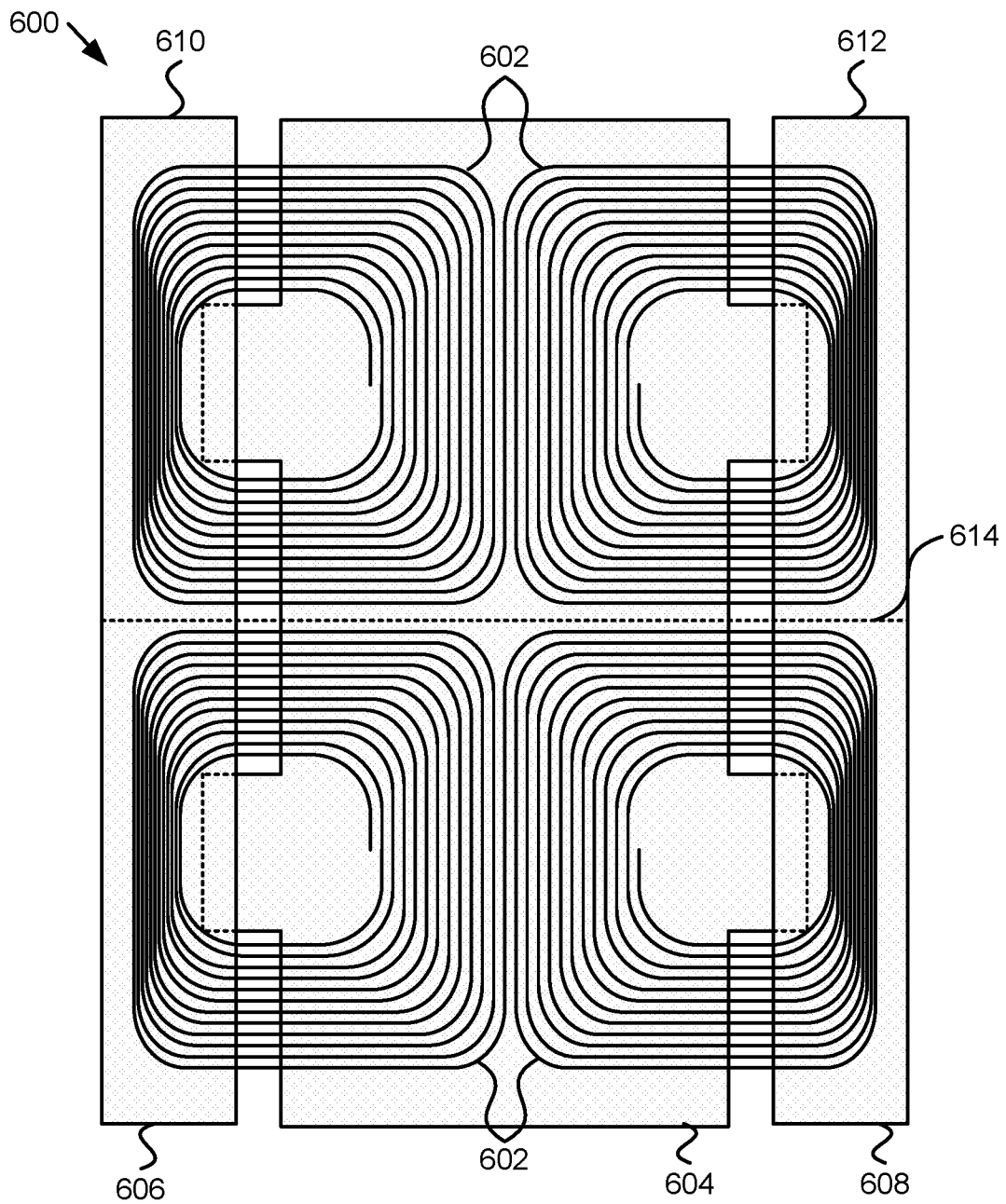


FIG. 6

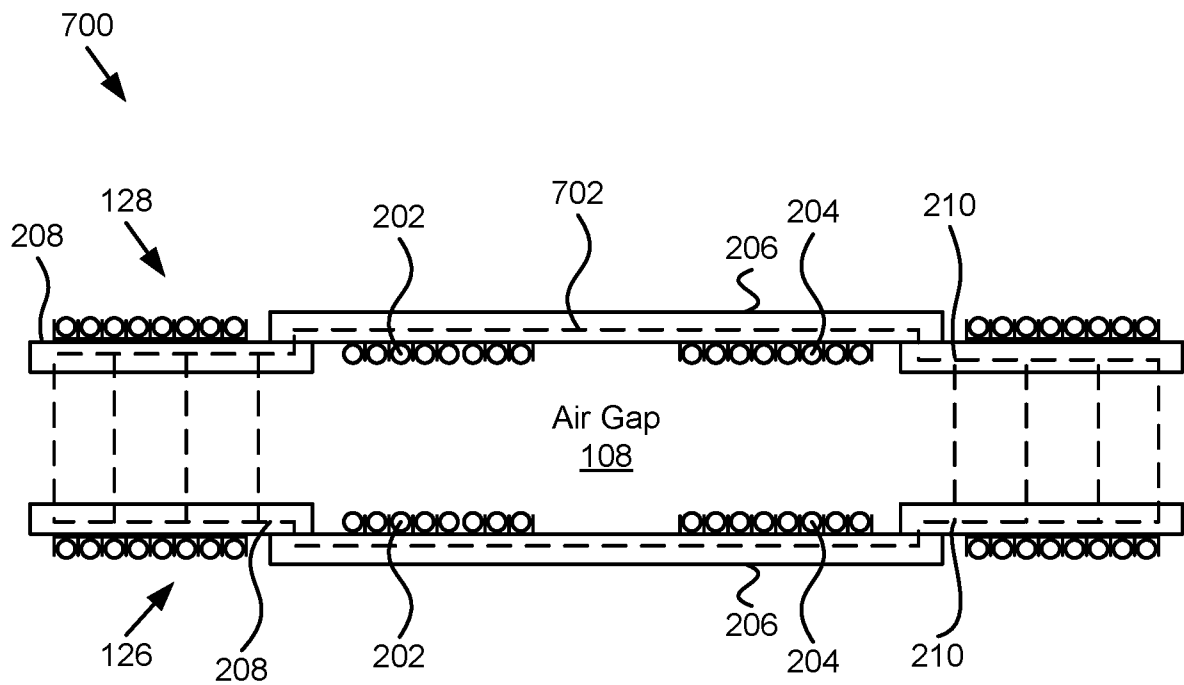


FIG. 7

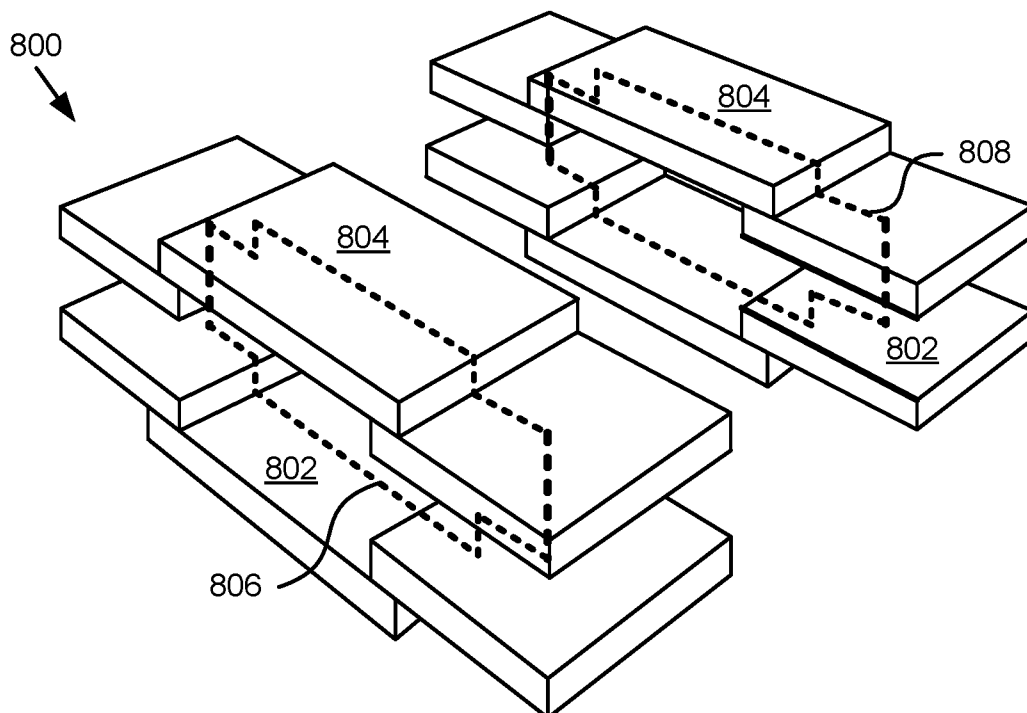


FIG. 8

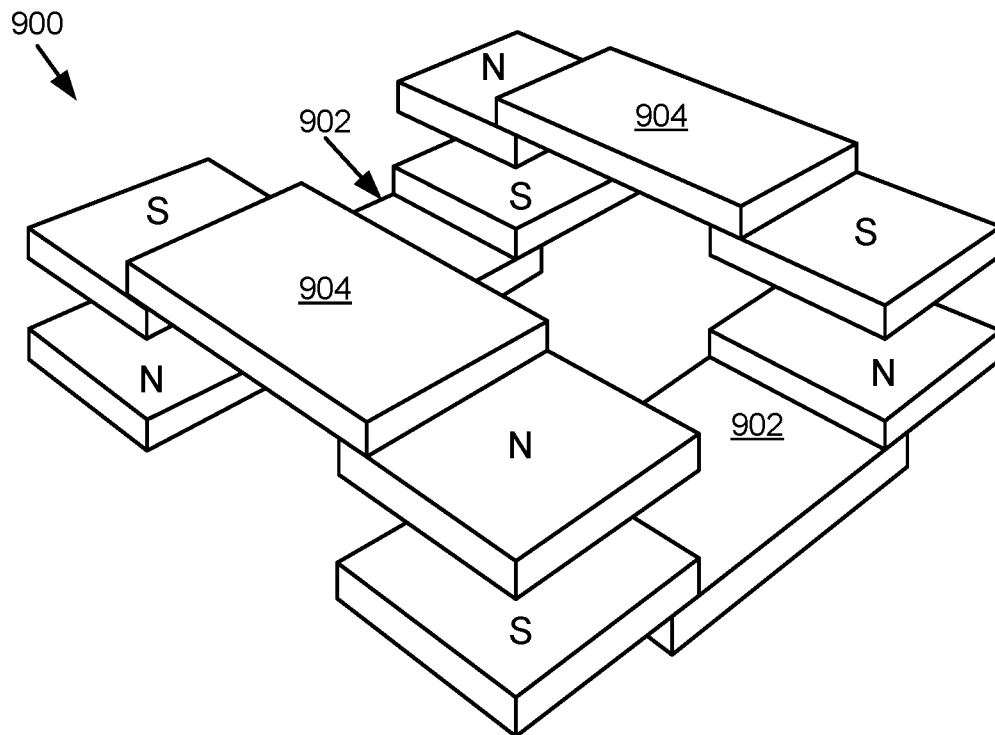


FIG. 9

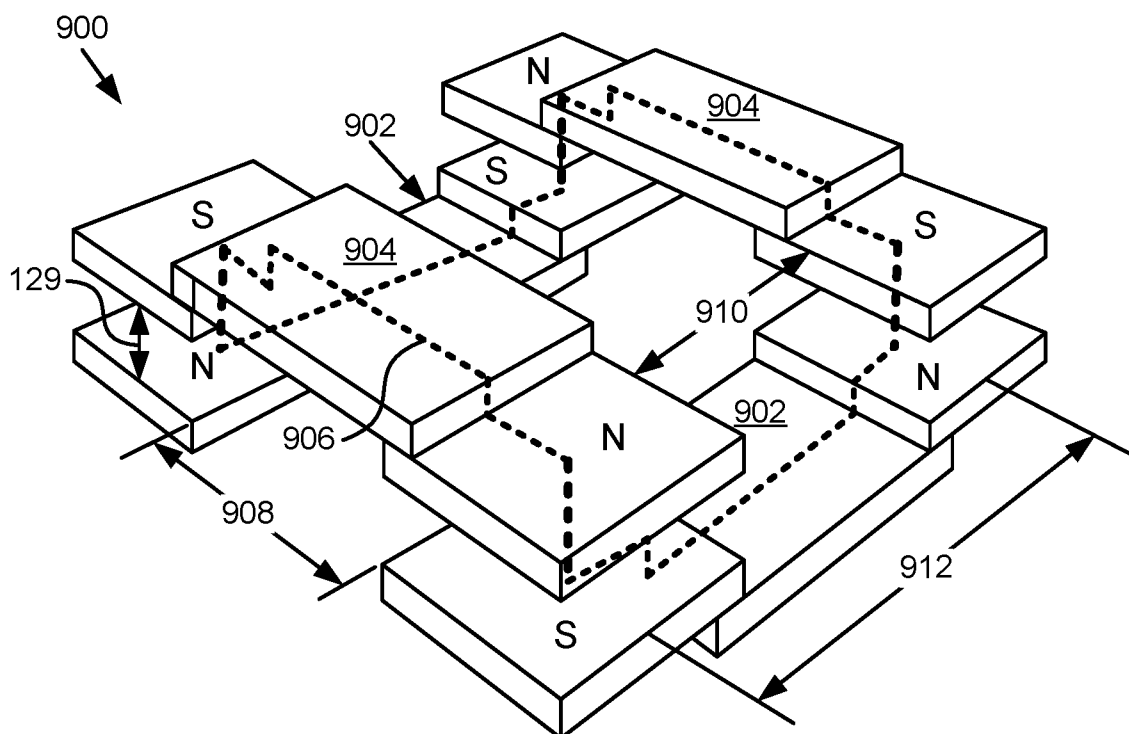


FIG. 10

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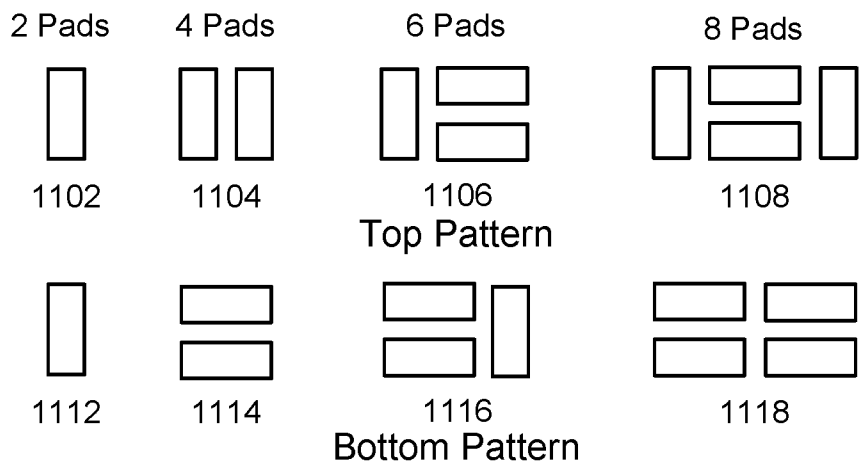


FIG. 11

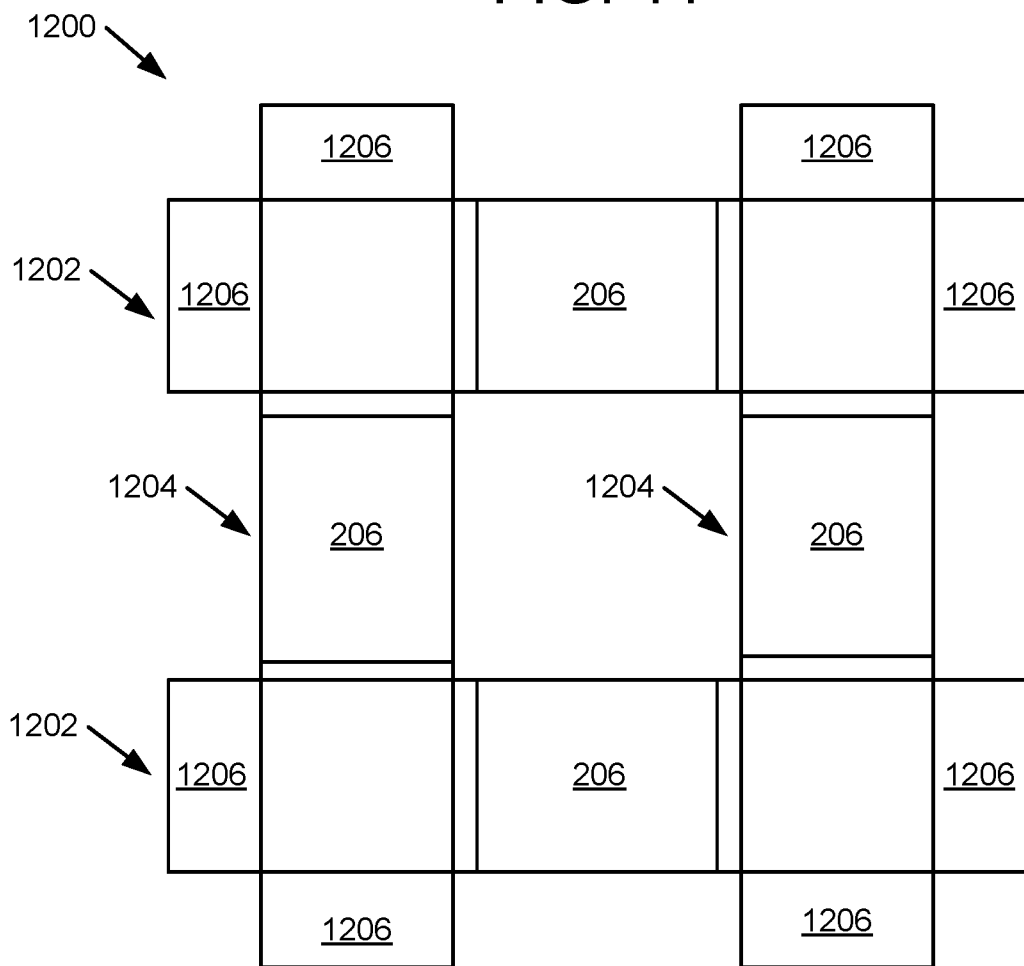


FIG. 12A

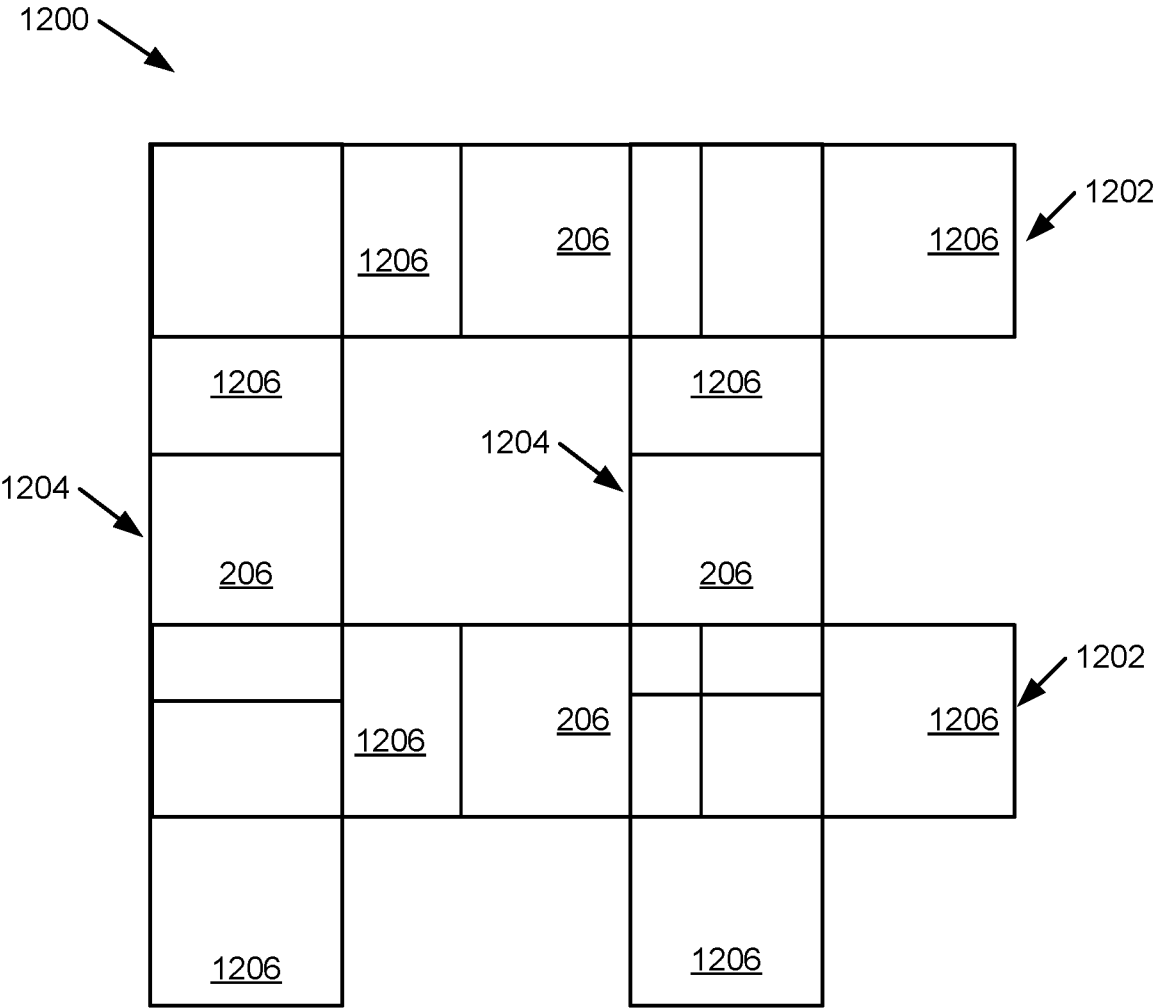


FIG. 12B

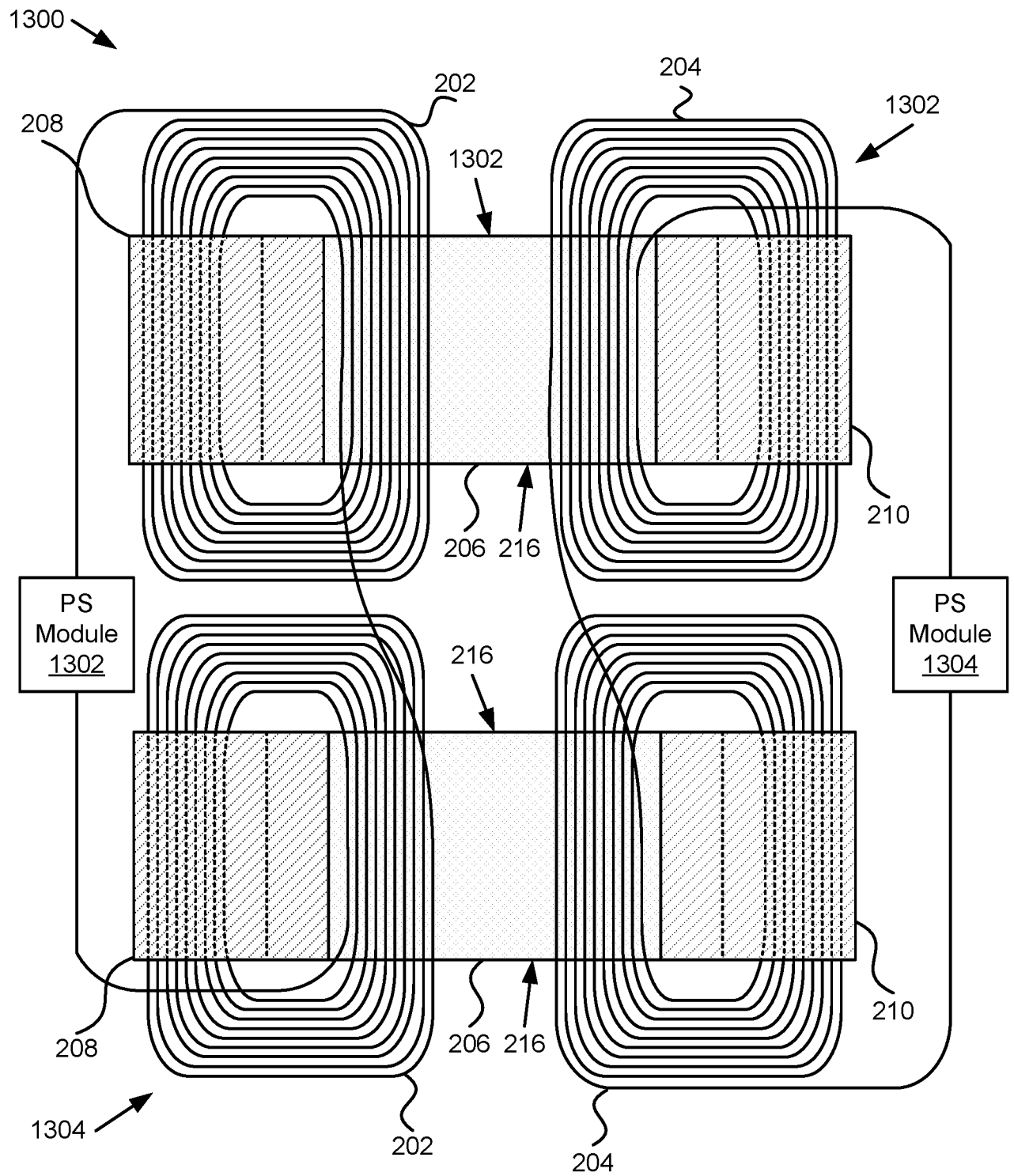


FIG. 13

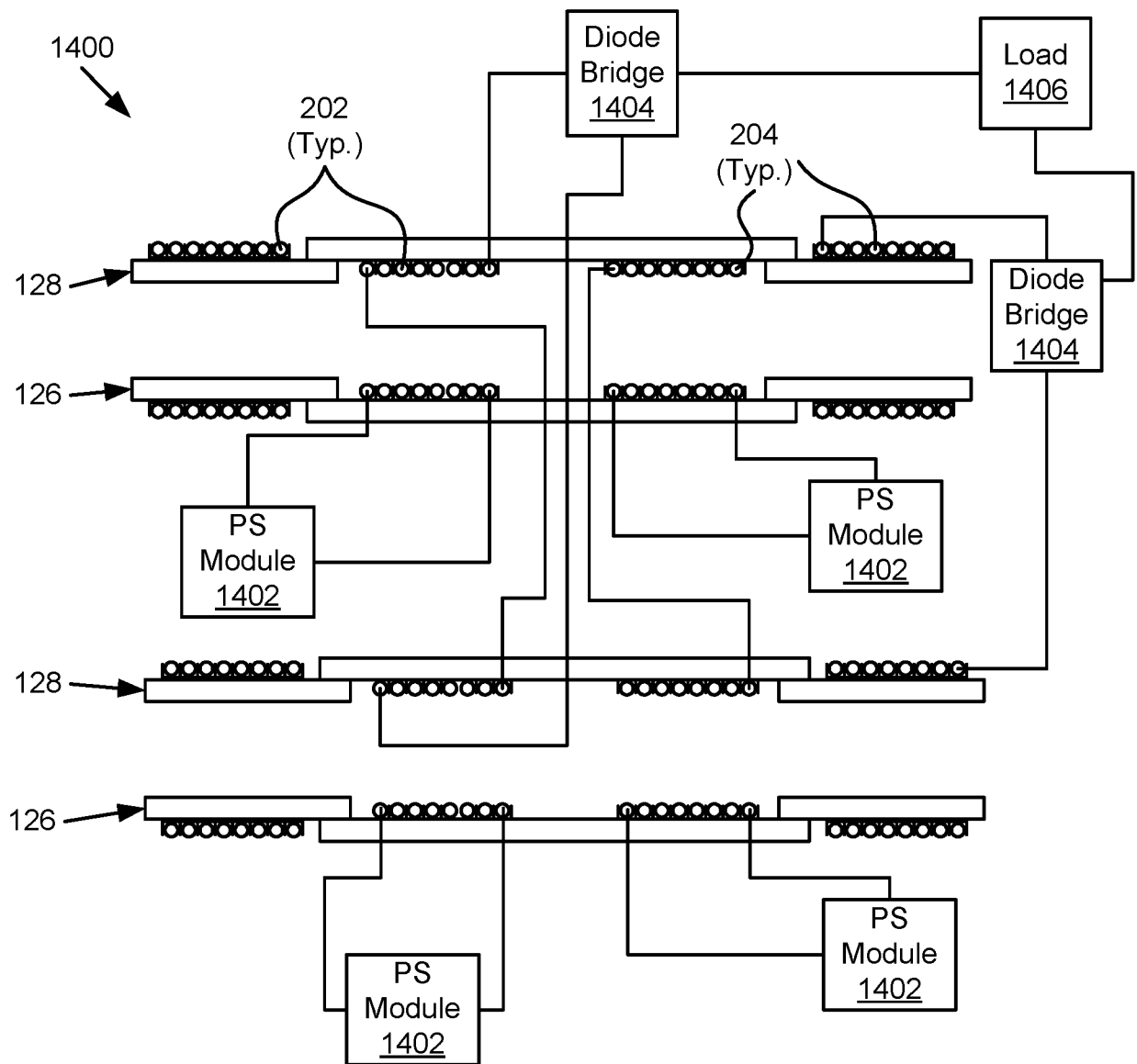


FIG. 14

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 2017/021971

A. CLASSIFICATION OF SUBJECT MATTER		
<i>H02J 50/10 (2016.01)</i>		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols)		
H02J 50/00, 50/10, 50/90		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
PatSearch (RUPTO internal), USPTO, PAJ, Esp@cenet, DWPI, EAPATIS, PATENTSCOPE		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2015/0170833 A1 (QUALCOMM INCORPORATED) 18.06.2015	1-60
A	US 2015/0364929 A1 (QUALCOMM INCORPORATED) 17.12.2015	1-60
A	RU 2505919 C1 (CORPORATION SAMSUNG ELECTRONICS CO., LTD.) 27.01.2014	1-60
☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "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) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search		Date of mailing of the international search report
29 June 2017 (29.06.2017)		14 August 2017 (14.08.2017)
Name and mailing address of the ISA/RU: Federal Institute of Industrial Property, Berezhkovskaya nab., 30-1, Moscow, G-59, GSP-3, Russia, 125993 Facsimile No: (8-495) 531-63-18, (8-499) 243-33-37		Authorized officer S. Chernyakova Telephone No. 8-499-240-25-91