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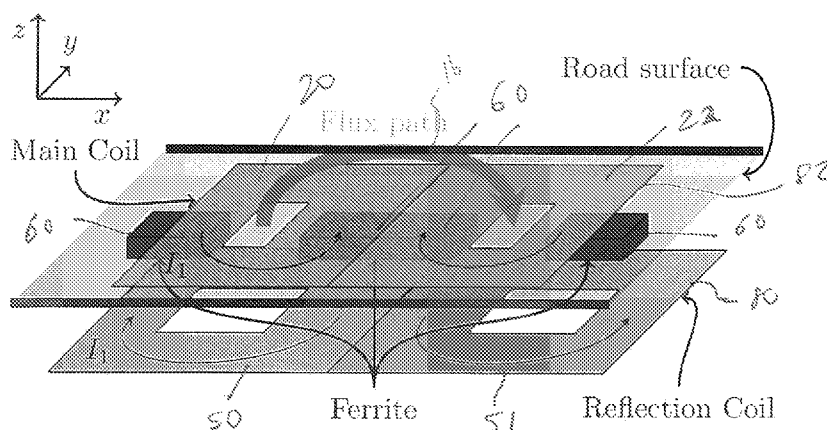


Figure 13

(57) Abstract: A wireless coupling structure has a first layer comprising a flux coupling coil having two opposing end regions separated by two opposing side regions; a second layer comprising a first block of ferrite and a second block of ferrite; and a third layer comprising a leakage flux control coil. The first block is provided next to one of the end regions and the second block is provided next to the other of the end regions.



WIRELESS POWER TRANSFER COUPLING STRUCTURES WITH REDUCED LEAKAGE FLUX

FIELD OF INVENTION

- 5 The disclosed subject matter relates to wireless power transfer, and in particular to magnetic coupling structures for facilitating wireless (or inductive) power transfer. Some applications of the disclosed subject matter include charging devices (including vehicles) wirelessly.

BACKGROUND

- 10 Wireless power transfer (WPT), which is also referred to as Inductive Power Transfer (IPT), is a safe and convenient technology that allows contactless high power transfer for many diverse applications. It has been applied in biomedical, materials handling, and cellphone charging and is now a practical solution for stationary Electric Vehicle (EV) wireless charging.

- Research into powering and charging EVs wirelessly while they are in motion is currently being undertaken. These systems are known as roadway systems, and distinguish themselves from
15 static charging and materials handling systems because they are located in public, outdoor and harsh environments.

- Determining the best wireless or magnetic coupler structure and geometry for systems is an important topic. These structures are commonly referred to as pads, since they are usually provided with a low profile, suitable for use on a desktop (for example to charge a cell phone),
20 or on a garage floor or roadway (for example to charge an EV). The term pads, when used in this document, refers to wireless power coupling structures.

- Most existing commercial pads use large quantities of a highly magnetically permeable material. This magnetic material is typically ferrite, so the term ferrite is used in this document to refer to suitably magnetically permeable materials for use with wireless coupling structures, but other
25 materials having similar properties may also be used. Ferrite has the advantage of significantly improving magnetic performance and power transfer, but has the disadvantage of being brittle and, if not suitable protected, may easily crack and degrade due to the high forces experienced in use, particularly in a roadway environment. Thus a roadway system with reduced ferrite is desirable. Aluminum is used in existing pads for shielding, but this is also undesirable in some
30 applications, such as a road surface, as it may corrode when exposed to the materials that make up the roadbed, such as concrete.

OBJECTS OF INVENTION

It is an object of the invention to provide a wireless power transfer coupling apparatus which will at least go some way toward overcoming disadvantages of existing apparatus or systems, or
5 which will at least provide a useful alternative to existing systems.

Further objects of the invention will become apparent from the following description.

SUMMARY OF INVENTION

10 In one aspect a wireless coupling apparatus is provided comprising:

a first layer comprising a flux coupling coil having two opposing end regions separated by two opposing side regions;

a second layer comprising a first block of highly magnetically permeable material and a second block of highly magnetically permeable material;

15 a third layer comprising a leakage flux control coil;

wherein the first block is provided proximate to one of the end regions and the second block is provided proximate to the other of the end regions.

In another aspect a wireless coupling apparatus is provided comprising:

20 a first layer comprising two flux coupling coils, each flux coupling coil having two opposing end regions separated by two opposing side regions, the flux coupling coils being located adjacent to each other with an end region of one coil being adjacent to the end region of the other coil;

25 a second layer comprising one or more blocks of highly magnetically permeable material;

a third layer comprising two leakage flux control coils;

wherein the block are provided proximate to those end regions of the flux coupling coils which are adjacent to each other.

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Preferably the second layer comprises a plurality of blocks of highly permeable material, each block being provided proximate to an end region.

Preferably the or each block does not extend to the side regions of the flux coupling coil.

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Preferably the flux coupling coils are positioned end to end in the first layer.

Preferably the flux coupling coils are substantially coplanar.

5 Preferably the or each flux coupling coil includes a central aperture.

Preferably the blocks do not extend across the aperture.

10 Preferably the or each leakage flux control coil is located relative to a corresponding flux coupling coil to control leakage flux from the flux coupling coil.

Preferably the leakage flux control coils are located end to end in the third layer.

15 Preferably the leakage flux control coils are substantially coplanar.

In another aspect a wireless coupling apparatus is provided comprising:

a first layer comprising a flux coupling coil;

a second layer comprising a highly magnetically permeable material;

a third layer comprising a leakage flux control coil;

20 wherein at least part of the periphery of the leakage flux control coil extends beyond a part of the periphery of the magnetically permeable material.

In another aspect a wireless coupling track or path is provided comprising a plurality of adjacent wireless coupling apparatus as claimed in any one of the preceding claims.

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In another aspect a roadway is provided including a track or path as set forth in any one of the preceding statements.

In another aspect a wireless coupling apparatus is provided comprising:

30 a first layer comprising a flux coupling coil having two opposing end regions separated by two opposing side regions;

a second layer comprising a plurality of blocks of highly magnetically permeable material;

a third layer comprising a leakage flux control coil;

35 wherein the blocks are provided proximal to the end regions of the flux coupling coil and do not extend to the side regions of the flux coupling coil.

In another aspect a wireless coupling apparatus is provided comprising:

a first layer comprising two flux coupling coils, each flux coupling coil having two opposing end regions separated by two opposing side regions, the flux coupling coils being located adjacent to each other with an end region of one coil being adjacent to the end region of the other coil;

a second layer comprising a plurality of blocks of highly magnetically permeable material;

a third layer comprising two leakage flux control coils;

wherein the blocks are provided proximal to the end regions of the flux coupling coil and do not extend to the side regions of the flux coupling coil.

Preferably the flux coupling coils are positioned end to end in the first layer

Preferably the flux coupling coils are substantially coplanar.

Preferably the or each flux coupling coil includes a central aperture.

Preferably the blocks do not extend across the aperture.

Preferably the or each leakage flux control coil is located relative to a corresponding flux coupling coil to control leakage flux from the flux coupling coil.

Preferably the leakage flux control coils are located end to end in the third layer.

Preferably the leakage flux control coils are substantially coplanar.

In another aspect a wireless coupling apparatus is provided comprising:

a first layer comprising a flux coupling coil;

a second layer comprising a highly magnetically permeable material;

a third layer comprising a leakage flux control coil;

wherein at least part of the periphery of the leakage flux control coil extends beyond a part of the periphery of the flux coupling coil.

In yet another aspect a wireless coupling track or path is provided comprising a plurality of adjacent wireless coupling apparatus as set forth in any one of the preceding statements.

In another aspect a roadway is provided which includes a track or path as set forth in the preceding statement.

As used herein the term “and/or” means “and” or “or”, or both.

5 As used herein “(s)” following a noun means the plural and/or singular forms of the noun.

The term “comprising” as used in this specification means “consisting at least in part of”. When interpreting statements in this specification which include that term, the features, prefaced by that term in each statement, all need to be present, but other features can also be present.

10 Related terms such as “comprise” and “comprised” are to be interpreted in the same manner.

It is intended that reference to a range of numbers disclosed herein (for example, 1 to 10) also incorporates reference to all rational numbers within that range (for example, 1, 1.1, 2, 3, 3.9, 4, 5, 6, 6.5, 7, 8, 9 and 10) and also any range of rational numbers within that range (for example,
15 2 to 8, 1.5 to 5.5 and 3.1 to 4.7).

The entire disclosures of all applications, patents and publications, cited above and below, if any, are hereby incorporated by reference.

20 The disclosed subject matter also provides method or system which may broadly be said to consist in the parts, elements and features referred to or indicated in this specification, individually or collectively, in any or all combinations of two or more of those parts, elements or features. Where specific integers are mentioned in this specification which have known equivalents in the art to which the invention relates, such known equivalents are deemed to be
25 incorporated in the specification.

Other aspects of the invention may become apparent from the following description which is given by way of example only and with reference to the accompanying drawings.

30 DRAWING DESCRIPTION

A number of embodiments of the invention will now be described by way of example with reference to the drawings as follows.

Figure 1 is a diagram showing an example of a high level overview of a wireless power transfer (IPT) system in an EV context, showing an in-ground primary coupler, and a secondary coupler associated with a vehicle.

Figure 2 is a diagrammatic plan view of the arrangement of Figure 1, showing a secondary pad in a vehicle overlaid on a primary pad located in a roadway.

Figure 3a is an isometric view showing a DD pad construction, and Fig 3b is a plan view showing dimensions of the Fig 3a constructions.

Figure 4 is a plan view illustrating dimensions of a secondary coupling structure.

Figure 5 is a diagrammatic isometric view of a path track or roadway showing a conceptual representation of a DD pad with: a) full ferrite base case (700mm x 525mm); b) RFDD (250mm x 100mm ferrite); c) RFDDwR (250mm x 100mm ferrite) with reflection coil of 760mm x 460mm and two turns out of phase with driven flux coupling winding.

Figure 6 is a diagrammatic isometric view of a simulation setup, showing primary pad (in this case the RFEWR), the secondary DD pad, the Airgap dimension and the X displacement and the Y displacement.

Figure 7 is a table of simulated values for pads discussed herein

Figure 8 is a series of plots showing leakage, inductance, current, field and VA for ferrite dimension

Figure 9 is a diagram in plan view of a DD construction

Figure 10 is a series of plots for varying depth of reflection coil.

Figure 11 is a series of plots for varying size of reflection coil

Figure 12 is a partial side elevation of a wireless power transfer primary structure having a main coil and a reflection coil located on a roadway next to an approaching vehicle tyre.

Figure 13 is a diagrammatic isometric view of a reduced ferrite DD pad, with a reflection or leakage flux control coil and ferrite at the edges of the pad.

Figure 14 is a series of plots illustrating the effect of ferrite at the end regions of the driving or main flux coupling coils.

Figure 15 is a series of plots for varying the size of the reflection coil in the Y dimension

Figure 16 is a summary of the results

Figure 17 shows dimensions of pad constructions disclosed herein.

Figure 18-20 show diagrammatic isometric views of track arrangements comprising pad structures according to the invention.

DESCRIPTION OF ONE OR MORE PREFERRED EMBODIMENTS OR EXAMPLES

5 This disclosure investigates the limits of strategic placement of small quantities of ferrite in a primary pad, and the improvements that can be gained from an additional coil (also referred to in this document as a reflection coil) which controls leakage flux and which is added below the primary flux coupling coil to help contain and shape the magnetic field produced or received by the pad.

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A background to roadway IPT systems is provided in patent publication WO2011/016736.

Background on a pad construction referred to in that document and in this disclosure as a DD pad (or Double D pad) is provided in WO2010/090539. Use of a reflection or leakage flux control coil that may be used to shape the field produced for coupling flux is disclosed in WO

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2016/039644. The disclosure of all these documents is incorporated herein by reference.

For ease of understanding the present disclosure, some general background in wireless power transfer systems is provided below.

20

Figures 1 and 2 depict a high level overview of an IPT system generally referenced 1. Such systems transfer power with the aid of a magnetic field between two loosely coupled wireless power coupling structures. The primary coupler is represented by inductor or coil L_1 and the secondary coupler by inductor or coil L_2 . In practice the coils are tuned using tuning capacitors which may be connected in series or parallel with coils L_1 and L_2 . The primary coupler is located in a roadway 4 and is energized by a power supply 2 to produce a magnetic field which is intercepted by the secondary coupler which is located in EV 3. The output of the secondary coupler is provided to a power conditioning circuit shown in Figure 1 as rectifier 5. The coordinate system (x,y,z) which is used in this disclosure is shown in Figure 1 and generally referenced 6. Choosing a suitable coupling (k) range for a given range of air gaps is needed to allow resonance and power transfer across the entire operating region.

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In any system, the power transferred is proportional to the secondary loaded quality factor of the tuned circuit (Q_2),

$$P_{OUT} = S_U Q_2,$$

where P_{OUT} is the output power and S_U is the secondary uncompensated output apparent power. Increasing Q_2 increases the output power, however there is a practical upper limit on Q_2 of around 10 in the secondary tuning network due to high circulating currents (when parallel tuned) or high voltages (when series tuned) and due to an increased system sensitivity to the narrow tuning band.

To determine S_U , the uncompensated secondary apparent power, the open circuit voltage ($V_{OC} = j\omega M_{12}I_1$) of the secondary pad can be multiplied by the short circuit current ($I_{SC} = V_{OC}/j\omega L_2$),

$$S_U = |V_{OC}||I_{SC}| = \omega \frac{M_{12}^2}{L_2} I_1^2 = \omega (k^2 L_1) I_1^2,$$

where I_1 is the current in the primary.

This can also be expressed more succinctly in terms of the primary and secondary VAs:

$$S_U = k^2 VA_1$$

where VA_1 is the VA of the unloaded primary pad inductor.

Since the focus of this disclosure is the comparison of pad magnetic topologies, the secondary loaded quality factor can be temporarily ignored to focus on only the magnetic design. Thus in this document S_U is used as the measure of output power capability, and higher is better. The pad referred to below in this document is designed to provide an S_U of 1kVA at nominal air gap under misalignment and when correctly loaded will allow a power transfer between 7-10kW, by increasing the circuit Q_2 .

The leakage magnetic field is also a critical metric for the acceptance of practical pad designs. In this disclosure, this is taken as the maximum RMS magnetic flux density (B_{RMS}) measured anywhere on a plane from the centre of the secondary pad in either the X or Y direction, and should be kept below the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines wherever people may be present. A distance from the center of the secondary pad is used which represents where a person might be standing at the side of a car, illustrated in Figure 2. Leakage is taken as the maximum value at the sides of the vehicle, from the center of the secondary pad. X leakage plane 7 and Y leakage planes 8 are shown in Figure 2.

Ultimately the objective when designing an IPT or WPT coupling system is to produce a system with a high power transfer and high efficiency with a low leakage magnetic field, but also with significantly improved robustness, which also functions over a large air gap between the primary and secondary pads. This disclosure presents means to achieve some of these objectives.

- 5 The following abbreviations are used in this document:

AFDD

Base case Full Ferrite Double D, with aluminium back-plane

FFDD

Full Ferrite Double D, no aluminium back-plane, set up as in lab

- 10 **RFDD**

Reduced Ferrite DD

RFDDwR

Reduced Ferrite DD with Reflection coil

RFDDwRwE

- 15 Reduced Ferrite DD with Reflection coil and with Extra ferrite

In this application, given the variable nature of the thickness of the pad (as the depth of the reflection coil into the road changes) the leakage in the Z direction is recorded as the maximum on a plane at a depth of 200mm below the top surface of the driven coil copper.

20

Comparison with Full Ferrite: FFDD

- To explore the suitability of the concept of using reduced, strategically located ferrite for use in an example of a roadway application, a pad was designed for the center of the Z2 air gap range, explained below. The pad has winding (Coil 20 and 22) outer dimensions of 640mm x 460mm and ferrite (Fe, 10) and aluminium back-plane or backplate (Al, 11) outer dimensions of 700mm x 525mm. A conceptual representation is shown in Fig. 3a, with dimensions in Fig. 3b. A ferrite relative permeability of 2500 is used for purposes of evaluation by simulation. The direction of current flow in the coils 20 and 22 is shown by arrows 12 and 14 respectively, and the flux path 16 is shown arching from the central pole area of coil 20 to the corresponding central pole area of coil 22. It should be noted that although a DD pad has two coil structures 20 and 22, they
- 25
- 30

may be wound from a single conductor or be electrically connected, so in some instances the coils 20 and 22 comprise a single electrical coil or winding.

The SAE J2954 standard specification defines the Z2 air gap region as the vehicle pad assembly to ground clearance, expecting the primary pad to be mounted on top of a road as a blister. This means that the copper to copper (i.e. coil to coil) air gap requirements are about 35mm lower than the ground to vehicle requirements, due to a traditional primary pad having about 40mm between the ground and the top of the copper coil, and the secondary pad having about 5mm of casing protecting the coils. The copper to copper air gap is the distance between the top surface of the ground assembly litz wire and the bottom surface of the vehicle assembly litz wire, and is ideal for magnetic analysis. Thus the Z2 copper to copper air gap requirements are around 105mm – 175mm.

To push towards the future requirements of higher power at higher air gaps and displacements, this disclosure focuses on a copper to copper air gap of 175mm, displaced to (75, 100) mm (x, y), and a WPT2 power level of 7kW. This deliberately pushes the base case ferrite system beyond its original designed copper to copper air gap of around 105-145mm, highlighting worst case leakage and coupling of existing systems, and steering the design towards these higher power requirements. This starts to explore the boundary of what is possible with current WPT systems and future ferrite-less systems.

Secondary Pad

A roadway system was created by coupling the FFDD primary described above with reference to Figure 3 to a secondary side DD pad shown in Figure 4 at a copper to copper air gap of 175mm .

The secondary pad of Figure 4 is a 2 turn 7-filar DD pad of dimensions 340mm x 260mm. The structural elements of the secondary pad shown in Figure 4 that are the same or equivalent to those of the primary pad have the same references as those of the primary pad. All the pad variations investigated in this document have this same secondary, and it is considered to be parallel tuned. The leakage contribution of the secondary pad is for the most part independent of the secondary tuning topology and number of turns of the coils.

Figure 5 shows conceptual representations of primary pad structures that show a progression from a FFDD structure shown in Figure 5(a), to two proposed structures RFE and RFEwR in Figures 5(b) and (c) respectively. The Figure 5 (b) and (c) structures have a much smaller amount of permeable material (ferrite) than the known structure of Figure 5(a). Figure 5(b) has a block of permeable material 10 which is located in the central region of the pad in a layer

beneath the coils 20 and 22, and between the pole areas at the center of each coil 20 and 22. Figure 5(c) incorporates the structure of Figure 5(b) but also includes a reflection coil layer comprising coils 50 and 51.

Testing performance of the proposed systems has been undertaken by simulation. An example of the simulation setup is shown in Fig. 6.

Simulation Results

To determine the magnetic parameters of the primary and secondary system of Figures 3 and 4, a simulation was run in JMAG Designer 14.1.01p, at an air gap of as discussed above. Figure 7 presents the key simulated values.

Leakage planes were placed in both the X and the Y direction at a distance away from the central axis of the system. If larger levels of power transfer are required, the pads or currents can be scaled.

Reducing the permeable material (Ferrite)

A DD pad of the type disclosed in Figures 3 and 4 is designed to channel the magnetic flux between its two poles, through a "flux pipe" on the underside of the pad and through the secondary pad above the pad. This may be seen in Figure 9. The two flux producing coils 20 and 22 are arranged in an adjacent manner side by side. These coils produce (or receive) coupling flux to couple the structure or pad to another flux coupler. The main coils may have a central aperture 24, 26. Each main coil may have opposing end portions (28, 29, 30, 31) and opposing side portions (32,33,34,35). The flux pipe spans the central end portions or regions 29, 31. The main coils represent a first layer in the construction. Ferrite 40 may be provided in a second layer (which may be planar) beneath the coils 20 and 22. A leakage flux control coil i.e. a reflection coil (which is not seen in this Figure) may be provided beneath the ferrite as a third layer (which may be planar).

To understand the best size of the ferrite 40 for exploring a reduced ferrite structure such as that of Figures 5(b) or 5(c), the ferrite sheet was changed for simulation purposes with the center coincident with the central axis of the coils, and increased by equal amounts in the positive and negative X and Y direction. Being rectangular, a DD pad has 2 lines of symmetry, one about the X axis and one about the Y axis.

In this evaluation, the aluminium backplate is removed completely, as is the gap between the ferrites which are typically provided as blocks. While aluminium certainly provides an effective

magnetic field shield, for the purposes of the evaluation in this section it is not considered. In addition, if it is not required in a roadway application that would save cost and issues with the aluminium reacting with the concrete.

Approximately 700 simulations were conducted in JMAG Designer 14.1.01p to produce the results shown in Figure 8, which shows how the key metrics of the pad change as the size of the ferrite is changed in the x and y directions, as in Figure 9. As illustrated in Fig. 8a the leakage in the X direction (when delivering to a fully displaced secondary at an airgap of 175mm) is lowest when the ferrite dimension is less than about 250mm in the X direction, and does not change much as the ferrite is extended in the Y direction. Interestingly, the leakage in the Y direction, shown in Fig. 8b shows a very similar result.

Fig. 8c and 8d can be combined to produce the primary VA_1 needed to deliver 1 kVA to the secondary, shown in Fig. 8e. This shows that as the size of the ferrite is increased, the VA_1 needed to deliver 1 kVA reduces. Note that, like the leakage, increasing the X dimension of the ferrite has more impact than increasing the Y dimension, and that, beyond a dimension of about 400 x 200 mm (x,y) further increases in the size of the ferrite do not decrease the VA_1 required to deliver 1 kVA to the secondary further.

As the ferrite increases beyond dimensions of around 400 x 200 mm (x,y) the leakage in both the X and Y direction starts increasing again. Thus for this particular investigation there is very little benefit in increasing the ferrite dimensions beyond 400 x 200 mm (x,y).

Decreasing the size of the ferrite reduces the leakage but increases the VA_1 required to deliver 1kVA to the secondary. A volume of ferrite of 250 x 100 x 10 mm (x,y,z) was chosen for a new pad construction, which consists of two 125 x 100 x 10 mm ferrite blocks. This is illustrated by the central rectangle in all the figures in Fig. 8. The dashed lines in all the figures in Fig. 8 illustrate where the driven (flux coupling) coil or coils 20, 22 are located. Thus the selected ferrite size is just inside the flux pipe of the driven coil.

The final plot, Fig. 8f illustrates the maximum flux density in the ferrite as the size of the ferrite back plane changes, while the primary is delivering to the secondary. This shows the opposite to the other graphs in that the Y dimension has the most impact on the B field in the ferrite, until the ferrite reaches around 100 mm wide in the Y direction. This indicates that there should be a certain minimum dimension of the ferrite in the Y direction to reduce the density of the magnetic field in the ferrite back plane. In this instance a ferrite Y dimension of 100 mm appears adequate (and aligns with the size of ferrites readily available in practice).

RFDD

As discussed above, the reduced ferrite size is chosen to be 250 x 100 mm, which corresponds to two 125 x 100 x 10 mm (x,y,z) blocks. The original FFDD comparison pad of Figure 3 had 28 of these blocks, so this represents a reduction in ferrite volume of 93%, for a reduction in leakage of 18% and 31% in the X and Y direction respectively. There is 11.6 times more leakage observed 200mm below the pad in the Z direction, and an increase in VA₁ of 49%.

A Z depth of 200mm from the top of the copper of the driven coil is chosen as it allows pads with reflection windings of different depths to be fairly compared. These are discussed in the following section.

Adding a Reflection Winding (or leakage flux control coil)

- 10 This concept has been described in previous patent literature, as identified earlier in this disclosure. A cancellation coil is used to cancel the unwanted or leakage magnetic field below the pad, and to the sides as well. It takes more VA to drive the reflection coil, but, when the reflection coil is well designed, the benefits in reduced leakage are compelling for some applications.
- 15 The simulations in this paper model the coils as a solid block of copper, a current density, whereas the physical construction is made up of discrete wires forming a coil. This is a valid assumption, even when there is a large gap between the wires. This is validated by the final constructed pads.

Depth of Reflection Winding

- 20 To begin to understand the benefits of the reflection winding on the RFDD, a reflection coil of the same dimensions as the driven coil was placed beneath the driven coil. The depth of this was varied from 40-200 mm, and the results processed. Fig. 10 shows the varying the depth of the reflection coil from 40-200mm, with ferrite dimensions 250 x 100mm. The leakage in the X and Y direction and the needed to deliver to the secondary are plotted for differing numbers of turns in the reflection coil.

- With an out of phase reflection coil of 2 turns, the lowest leakage in the X direction of 21 uT is when the depth of reflection coil is 160 mm, giving a VA₁ of 167.9. This represents a decrease in X leakage of about 10% for an increase in of about 9%. As can be seen from the graphs of Figure 10, the reduction in leakage is proportional to N , but the increase in appears to be proportional to N^2 . Two turns of the reflection coil is a good compromise between reduction in leakage, increase in VA₁ and increase in copper volume, but other configurations can be chosen depending on what is preferred in the application. In general, the deeper the reflection coil, the less the VA₁ changes.

As a comparison, an aluminium sheet of the same dimensions as the reflection coil was simulated at the same set of depths (40-200 mm). As the depth increases, the leakage increases, until, when the aluminium is at a depth of 200mm, the aluminium sheet has no impact on the leakage in the X direction (compared to having no reflection coil or aluminium at all), and actually increases the leakage in the Y direction. At the other extreme, when the aluminium is at a depth of 40mm, the leakage is reduced by about 10% compared to no reflection coil, but the VA_1 has increased by around 35%. The depths where the aluminium and the reflection coil (with different turns) have the same leakage, for $N = 2$ the leakage is reduced by about 8% at a depth of 80mm, but the VA_1 for the aluminium is much higher (off this chart). For $N = 1$, the leakage is about the same as the aluminium when the depth is about 130mm. At 130mm depth, the single turn reflection coil has a lower VA_1 than the aluminium, for the same reduction in leakage.

This indicates that a reflection coil allows more control of the leakage field for a lower VA_1 cost than an equivalently sized and placed aluminium sheet.

Depth and extension of Reflection Winding

Another set of simulations were run extending the size of an aluminium back plane located in the same place as the reflection coil, providing a comparison with the reflection coil. The results are shown in Fig. 11. These results show that, in general, when the reflection coil X dimension is the same as the driven coil X dimension, the deeper the reflection coil, the lower the leakage in the X direction.

However, if the size of the reflection coil is extended to 900mm in the X direction, the depth of the reflection coil is not very dependent on the depth of the reflection coil, being about a 20% reduction in leakage across the three reflection coil depths investigated.

Another interesting aspect to look at is the increase in the VA_1 required to deliver power to the secondary. As would be expected, the shallower the reflection coil is (the closer it is to the driven coil) the more impact changing its X dimension has on the VA_1 required. Looking at just $N = 2$, in general, as the X dimension of the pad increases the higher the VA_1 requirement (with a corresponding decrease in LPP X).

These results show that as long as the reflection coil is made larger the depth of the reflection coil makes little difference. This allows the pad to be shallow, with the reflection coil at a depth of 40mm.

The aluminium simulation results (listed as "Aluminium" in the key or legend in Fig. 11) show that as the depth of the aluminium increases, the leakage increases and the VA_1 decreases,

which is intuitive as the circulating currents in the aluminium will be lower as it moves further away from the driven coil. At 100mm depth the aluminium behaves similarly to a reflection coil of two turns, and at 160mm depth it behaves much like a reflection coil of one turn. At a depth of 40mm, our preferred depth, the aluminium greatly increases the VA_1 requirement of the pad, for the same reduction in X leakage if the reflection coil is extended to 860mm. This is a good example of the benefits of a well-designed reflection coil, as it can reduce the leakage significantly for a relatively small increase in VA_1 (compared to the aluminium at 40mm depth).

Again, looking at Fig. 11, in general as the X dimension increases the leakage in the X direction decreases and the VA_1 increases linearly. This begs the question then, what size to make the reflection coil, given a reduction in the leakage in the X direction and the ferrite is desired for this roadway IPT application.

There are two ways to bound the increase in X dimension, one is VA_1 , which should be no more than $2 \times$ the full ferrite one, or $2 \times 103 \approx 200$ kVA. With a reflection coil of two turns, the all the pads in Fig. 11 meet that requirement.

The other one is the area of the pad, which can be extended somewhat given the intended application of this pad, above ground "blister" packaging, or flush mounting. In the short term, blister mounting is more pertinent, so the reflection coil would be limited by that packaging. Fig. 12 explores this. As the blister is sloped to allow the wheel 100 to roll over the pad, the extra space at the bottom can be used to extend the reflection coil. With a reflection coil of dimensions 760mm, the angle of the blister is 31 degrees, which seems about right.

Thus as an example design the dimensions of the reflection coil are chosen to be 760 x 460 mm, with a two turn reflection coil, driven out of phase with the driven coil.

Adding Ferrite at the edge of the pad

Given that the DD pad has more leakage in the X direction than the Y direction, it is worth strategically placing ferrite to reduce this leakage. Fig. 8 indicates that adding reflection along the central X axis could reduce the leakage in the X direction and the VA. Such a concept would look like Fig. 13. In Figure 13, the reflection or leakage flux control coils 50 and 51 are shown. These are provided in a third layer beneath the ferrite layer. As can be seen, the ferrite layer comprises blocks 60, each block being magnetically associated with the end region of each of the main (driven in the case of a primary) flux coupling coils. The ferrite blocks do not extend to the side regions of the main coils 20 and 22. The ferrite does also not extend across the aperture (or pole region) of each of the main coils 20 and 22. Another way in which to consider this construction is that the main coils 20 and 22 have end regions that comprise conductor

segments extending along the y axis, and side regions the comprise conductor segments extending along the x axis. The ferrite is located at the conductor segments along the y axis.

To compare with previous evaluations, Fig. 14 shows what happens with a reflection coil (or aluminium) is added at a depth of 40 mm, and then extended in the reflection coil in the X direction only (Y dimension is the same as the driven coil). Thus Fig. 11a and Fig. 14 are directly comparable, just with additional edge ferrite added.

Comparing Fig. 11a and Fig. 14, the black line represents no reflection coil or aluminium present ($N = 0$). By adding the additional edge ferrite the LPP in the X direction has decreased from about 23.5 to about 20 at the expense of an increase in from about 158kVA to about 160kVA, which is a good trade, given the large decrease in leakage and small increase in VA. The leakage in the Y direction has also decreased by adding the additional edge ferrite.

When the reflection coil is added to the pad with additional edge ferrite the LPP decreases even further, for only a slight increase in , again a worthy trade considering how much of a reduction in leakage is obtained. Looking mainly at $N = 2$, this gives a significant reduction in leakage, for a small increase in VA .

Once again, adding the aluminium sheet at 40mm depth decreases the leakage significantly, but increases the even more so. Given that when using the aluminium the huge increase in to get almost the same reduction in leakage as with the two turn reflection coil, it is better to use the two turn reflection coil.

Extending the reflection coil beyond the ferrite 60 allows the reflection coil to be more effective in controlling the unwanted leakage flux. Thus as shown in Figure 13, a part of the periphery 80 of the reflection coil extends beyond a periphery 82 of the ferrite (or ferrite layer). In this way the reflection coil has a closer magnetic association with the coil 22 which is producing the coupling flux.

Reducing Reflection Coil in Y Direction

Given increasing the dimension of the reflection coil in the X direction reduces the leakage in the X direction, and does not impact leakage in the Y leakage significantly, it seems reasonable to reduce the Y dimension of the reflection coil to attempt to reduce the VA_1 . The nature of the DD pad is that X dimensions contribute more strongly to leakage overall, so reducing the Y dimension of the reflection coil should have little impact on the X and Y leakage. In any case the leakage in the Y direction is significantly lower than the leakage in the X direction, so increasing it a little will not impact the maximum leakage of the pad. Reducing the area of the reflection coil (by reducing the Y dimension) should decrease the overall VA_1 needed to drive the pad.

The X dimension of the reflection coil was fixed at 760mm and the depth at 40mm.

Fig. 15 shows the results of reducing the Y dimension. Looking at the results, reducing the Y dimension of the reflection coil increases the leakage in both the X and Y direction, as expected, but not by very much. The VA_1 decreases as the Y dimension decreases, but again, not by very much. It appears that the VA_1 :leakage X tradeoff is approximately linear, and gradual. Thus decreasing the Y dimension appears to have some, but little benefit.

Something to note from Figure 7 is that the variation in primary inductance is less when there is less ferrite in the primary pad. This means the system will be better tuned across its operating range.

Fig. 16 shows the overall simulated results, and Figure 17 summarizes the dimensions of structures disclosed in this document.

In Figure 18, a number of DD structures as disclosed above are provided in the form of a path or track. As can be seen, the structures may be energized to provide flux paths 70, so that power may be transferred to a moving object. The ferrite 60 is placed to also provide a flux path 71 between adjacent pads. This concept may be extended to structures that comprise a single flux coupling coil and a single reflection coil. Such structures, when placed adjacent to each other to form a track are shown in Figures 19 and 20, with flux path 70 and 72.

This disclosure has explored what happens if ferrite is reduced in a coupling structure (particularly DD) topologies, and has presented solutions for the best placement of small volumes of permeable material such as ferrite. In general the ferrite should be placed in the centre of the pad in the flux pipe and the X dimension of the ferrite is more important than the Y dimension. The Y ferrite dimension should be at least around 1/5th of the copper dimension. To minimise the leakage the ferrite should be smaller and to minimise the VA the ferrite should be larger.

A reflection coil can be placed below the driven coil and reduced ferrite to further decrease the leakage. A reflection coil allows more control over the leakage for a lower cost than an equivalent aluminium sheet. When the reflection coil is smaller in area it reduces the leakage more when it is deeper. However, when the reflection coil is larger the depth of the reflection coil makes less of a difference on the leakage and VA.

Extra ferrite can be added at the edges of the pad where it further reduces the leakage in the X direction for only a small increase in VA.

The final design presented RFDDwRwE has a very low leakage in the X and Y direction, an increase on only 2.8 times the leakage in the Z direction and an increase in of 72% when displaced at an air gap of 175mm. The pad is only around 50mm thick, with a pad area of 760 x 460mm, with $\frac{1}{7}$ th the volume of ferrite that was in the base case pad. This smaller ferrite block would be easier to protect and cheaper to manufacture.

Throughout the description like reference numerals will be used to refer to like features in different embodiments.

The terms “inductive power transfer” can be substituted with “transcutaneous energy transfer” which is commonly used terminology when referring to powering of implanted medical devices.

The entire disclosures of all applications, patents and publications cited above and below, if any, are herein incorporated by reference. Any discussion of the prior art throughout the specification should in no way be considered as an admission that such prior art is widely known or forms part of common general knowledge in the field.

Unless the context clearly requires otherwise, throughout the description, the words “comprise”, “comprising”, and the like, are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense, that is to say, in the sense of “including, but not limited to”.

Although this invention has been described by way of example and with reference to possible embodiments thereof, it is to be understood that modifications or improvements may be made thereto without departing from the scope of the invention. The invention may also be said broadly to consist in the parts, elements and features referred to or indicated in the specification of the application, individually or collectively, in any or all combinations of two or more of said parts, elements or features. Furthermore, where reference has been made to specific components or integers of the invention having known equivalents, then such equivalents are herein incorporated as if individually set forth.

It should be noted that various changes and modifications to the presently preferred embodiments described herein will be apparent to those skilled in the art. Such changes and modifications may be made without departing from the spirit and scope of the invention and without diminishing its attendant advantages. It is therefore intended that such changes and modifications be included within the present invention.

CLAIMS

1. A wireless coupling apparatus comprising:

a first layer comprising a flux coupling coil having two opposing end regions separated by two opposing side regions;

a second layer comprising a first block of highly magnetically permeable material and a second block of highly magnetically permeable material;

a third layer comprising a leakage flux control coil;

wherein the first block is provided proximate to one of the end regions and the second block is provided proximate to the other of the end regions.

2. A Wireless coupling apparatus comprising:

a first layer comprising two flux coupling coils, each flux coupling coil having two opposing end regions separated by two opposing side regions, the flux coupling coils being located adjacent to each other with an end region of one coil being adjacent to the end region of the other coil;

a second layer comprising one or more blocks of highly magnetically permeable material;

a third layer comprising two leakage flux control coils;

wherein the block are provided proximate to those end regions of the flux coupling coils which are adjacent to each other.

3. The apparatus as claimed in claim 2 wherein the second layer comprises a plurality of blocks of highly permeable material, each block being provided proximate to an end region.

4. The apparatus as claimed in any one of the preceding claims wherein the or each block does not extend to the side regions of the flux coupling coil.

5. The apparatus as claimed in claim 2 wherein the flux coupling coils are positioned end to end in the first layer.

6. The apparatus as claimed in any one of the preceding claims wherein the flux coupling coils are substantially coplanar.

7. The apparatus as claimed in any one of the preceding claims wherein the or each flux coupling coil includes a central aperture.
8. The apparatus as claimed in claim 7 wherein the blocks do not extend across the aperture.
9. The apparatus as claimed in any one of the preceding claims wherein the or each leakage flux control coil is located relative to a corresponding flux coupling coil to control leakage flux from the flux coupling coil.
10. The apparatus as claimed in any one of claims 2 to 9 wherein the leakage flux control coils are located end to end in the third layer.
11. The apparatus as claimed in any one of claims 2 to 10 wherein the leakage flux control coils are substantially coplanar.
12. A wireless coupling apparatus comprising:
a first layer comprising a flux coupling coil;
a second layer comprising a highly magnetically permeable material;
a third layer comprising a leakage flux control coil;
wherein at least part of the periphery of the leakage flux control coil extends beyond a part of the periphery of the magnetically permeable material.
13. A wireless coupling track or path comprising a plurality of adjacent wireless coupling apparatus as claimed in any one of the preceding claims.
14. A roadway including a track or path as claimed in claim 13.

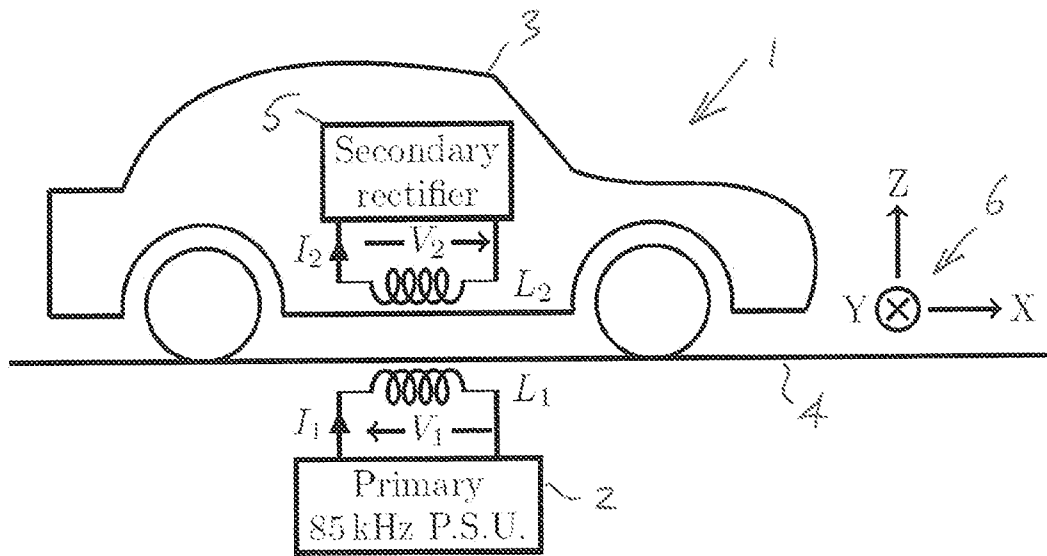


Figure 1

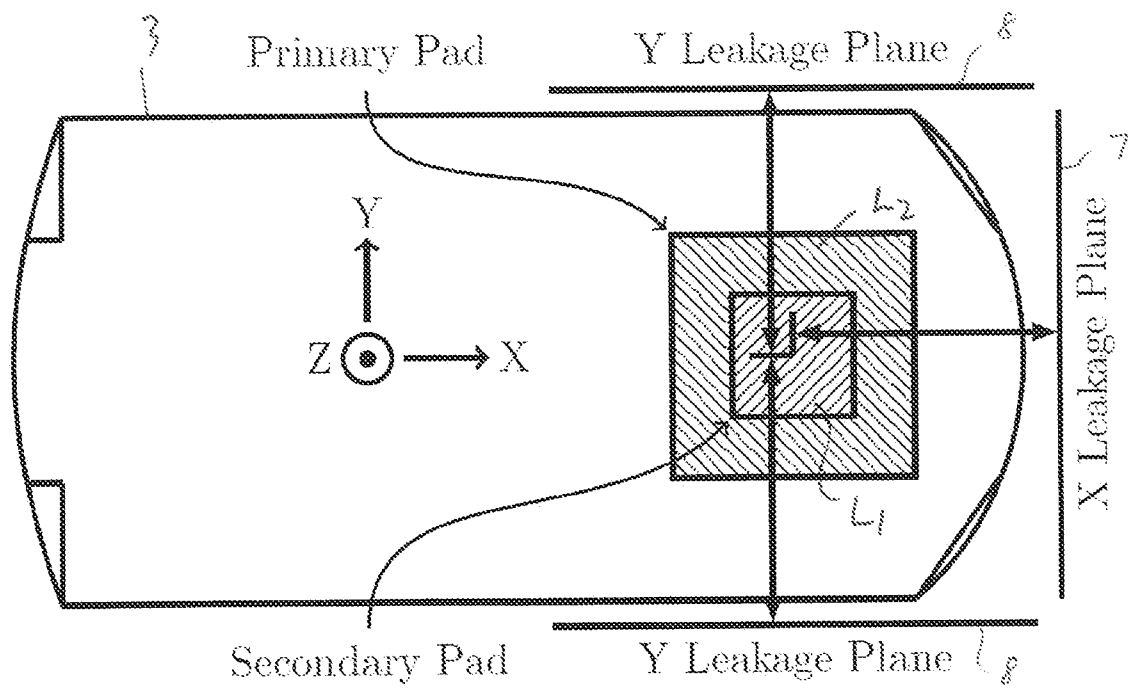


Figure 2

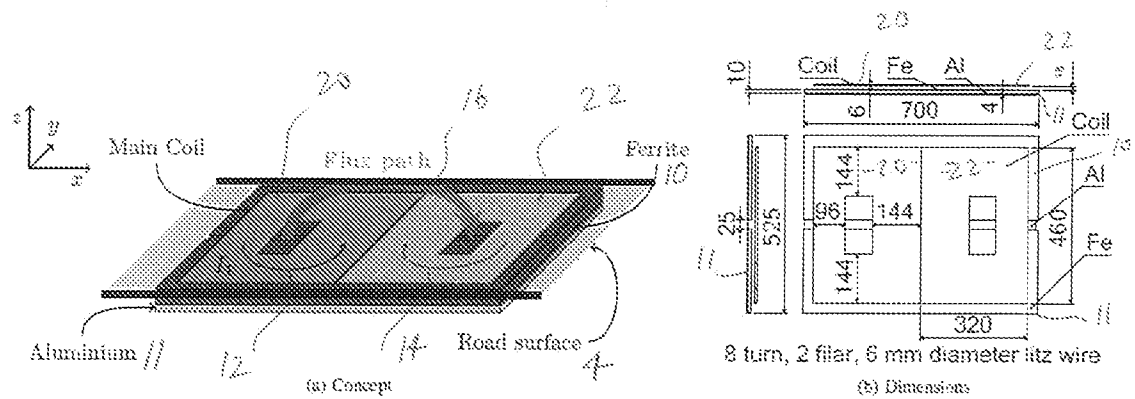
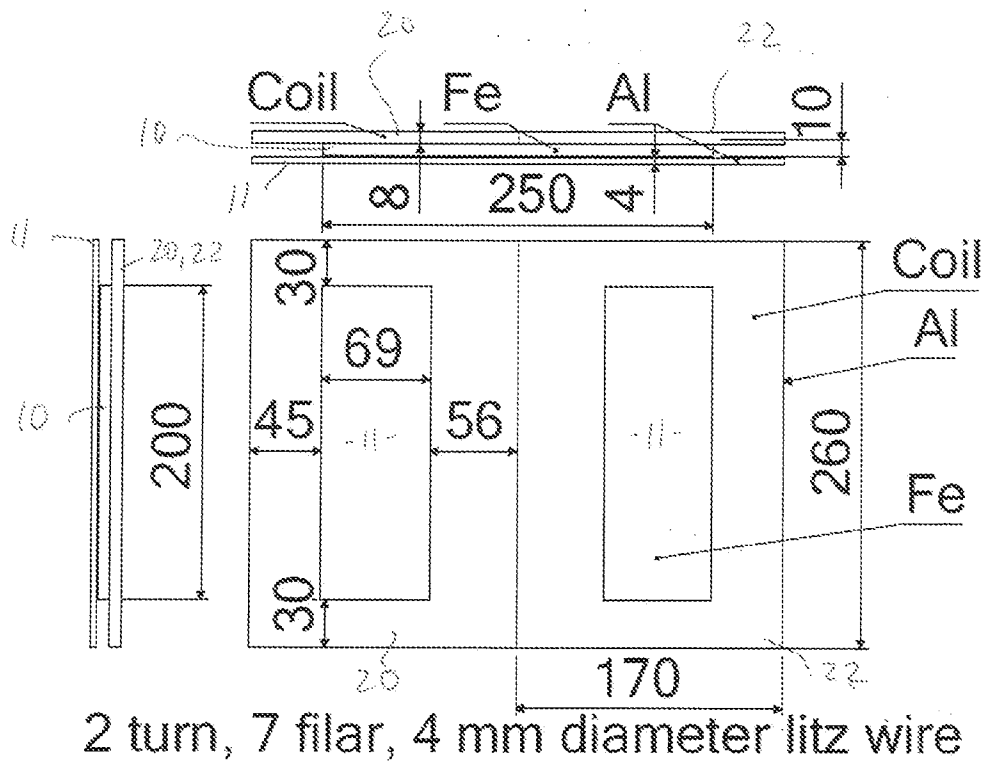


Fig. 3: The base case DD pad, (a) conceptual drawing and (b) dimensions.

Figure 3



Dimensions of the secondary.

Figure 4

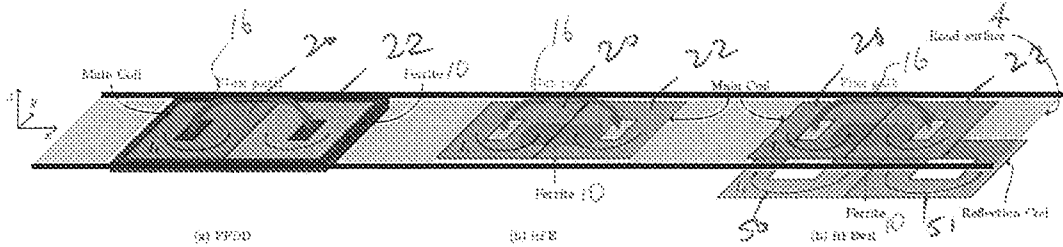


Fig. 5: Conceptual representation of DD pad with (a) full ferrite base case (700 x 525 mm ferrite) (b) RFDD (250 x 100 mm ferrite) (c) RFDDwR (250 x 100 mm ferrite) with reflection coil of 760 x 460 mm and 2 turns out of phase with driven winding

Figure 5

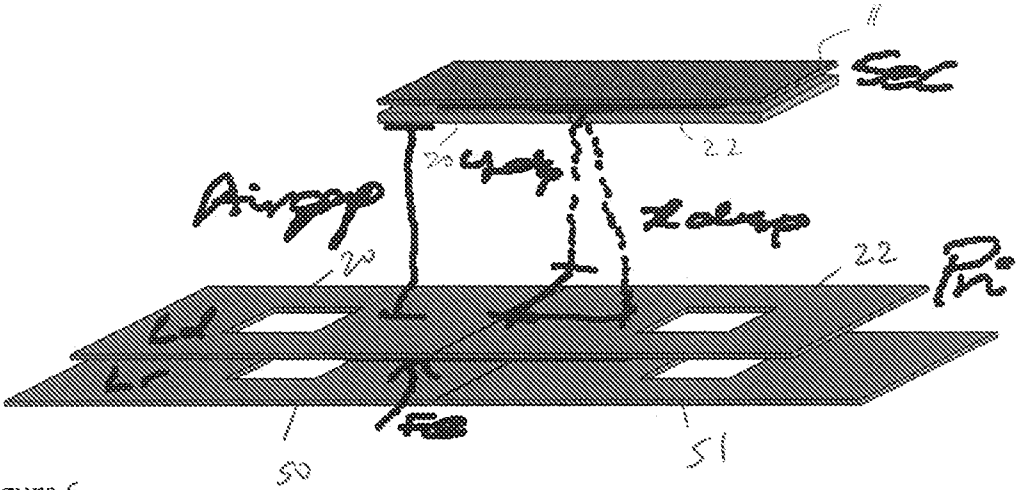


Figure 6

TABLE I: Key simulated values for the pads discussed in this paper, centred and displaced to (75, 100) mm (x, y) at an air gap of 175 mm. See Fig. ?? for graphical representation of this data. The I_1 , VA_1 and leakage values reported here are with the I_1 required to deliver 1 kVA to the secondary. Leakage in X and Y is the maximum on a plane 800 mm from the centre of the secondary, and leakage in Z is the maximum on a plane 200 mm below the top copper surface of the driven coil.

	Pad	Corresponding Figures	L_1 (μ H)	L_2 (μ H)	k	I_1 A _{RMS}	VA_1 kVA	$B_{RMS}(X)$ (μ T)	$B_{RMS}(Y)$ (μ T)	$B_{RMS}(Z)$ (μ T)
AG 100 Centred (0, 0)	AFF		68.5	4.26	0.2851	18	12	6.7	2.9	9.3
	FFE		68.6	4.26	0.2850	18	12	6.6	2.7	8.9
	RFE		47.4	4.16	0.2544	25	15	4.6	1.6	111.7
	RFEwR		41.2	4.16	0.2513	27	16	4.2	1.7	41.7
	RFEwRwE	..	44.8	4.16	0.2468	26	16	3.0	1.3	32.4
AG 175 Displaced (75, 100)	AFF		64.6	4.11	0.0979	55	105	29.5	13.7	29.0
	FFE		61.7	4.11	0.0978	55	105	29.0	13.2	27.3
	RFE		43.4	4.06	0.0890	80	156	24.2	9.5	366.4
	RFEwR		39.4	4.07	0.0758	91	174	22.0	9.8	148.1
	RFEwRwE	..	43.0	4.07	0.0743	89	161	16.9	8.3	111.4

Figure 7

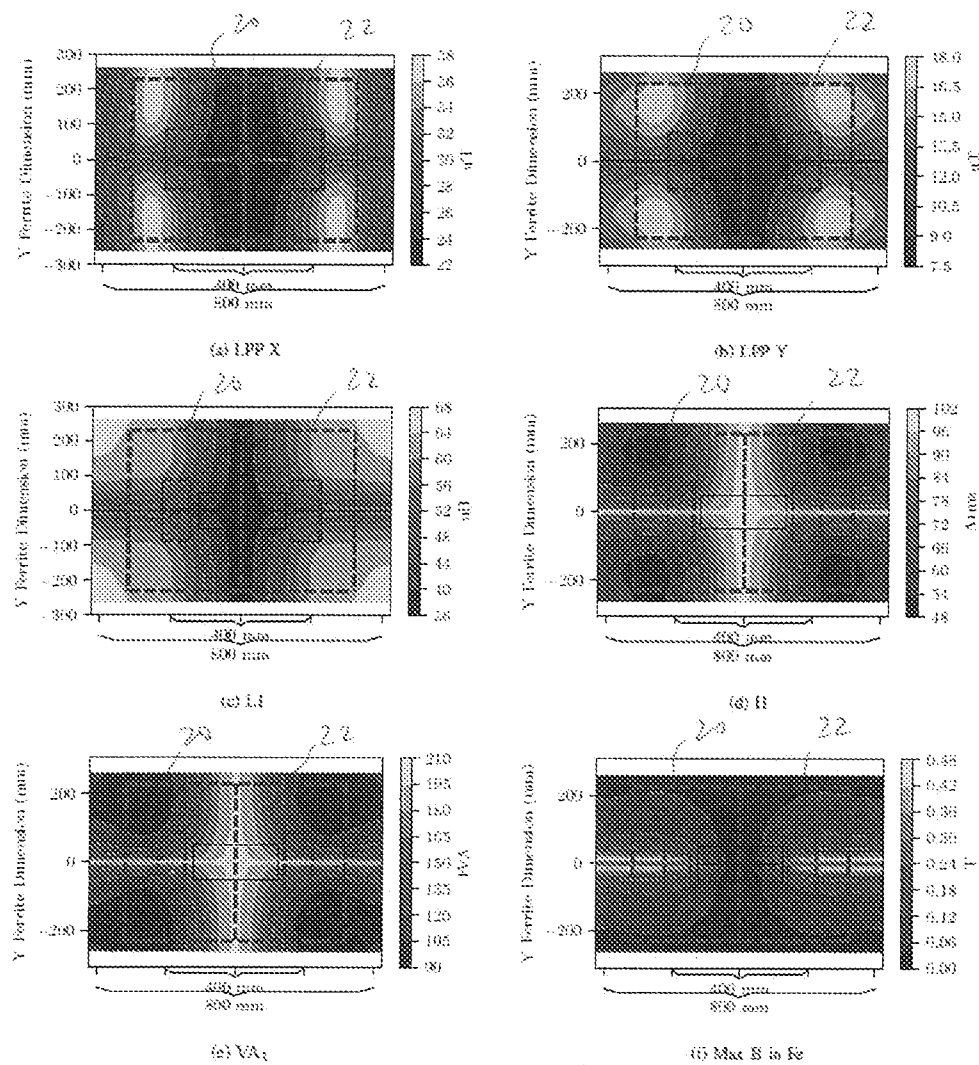


Fig. With the secondary at a copper to copper air gap of 175 mm and displaced to 75, 100 mm (x, y). Note the red dots showing the points of interest. Contour plots showing the value of (a) LPP X, (b) LPP Y, (c) LI, (d) II, (e) VA1 and (f) max B in Fe as the ferrite X dimension and ferrite Y dimensions are varied. Leakage is taken on a plane 800 mm away from the centre of the secondary, or in the case of the Z leakage, 800 mm down (-Z) from the top of the primary. In general lower (blue) is better.

Figure 8

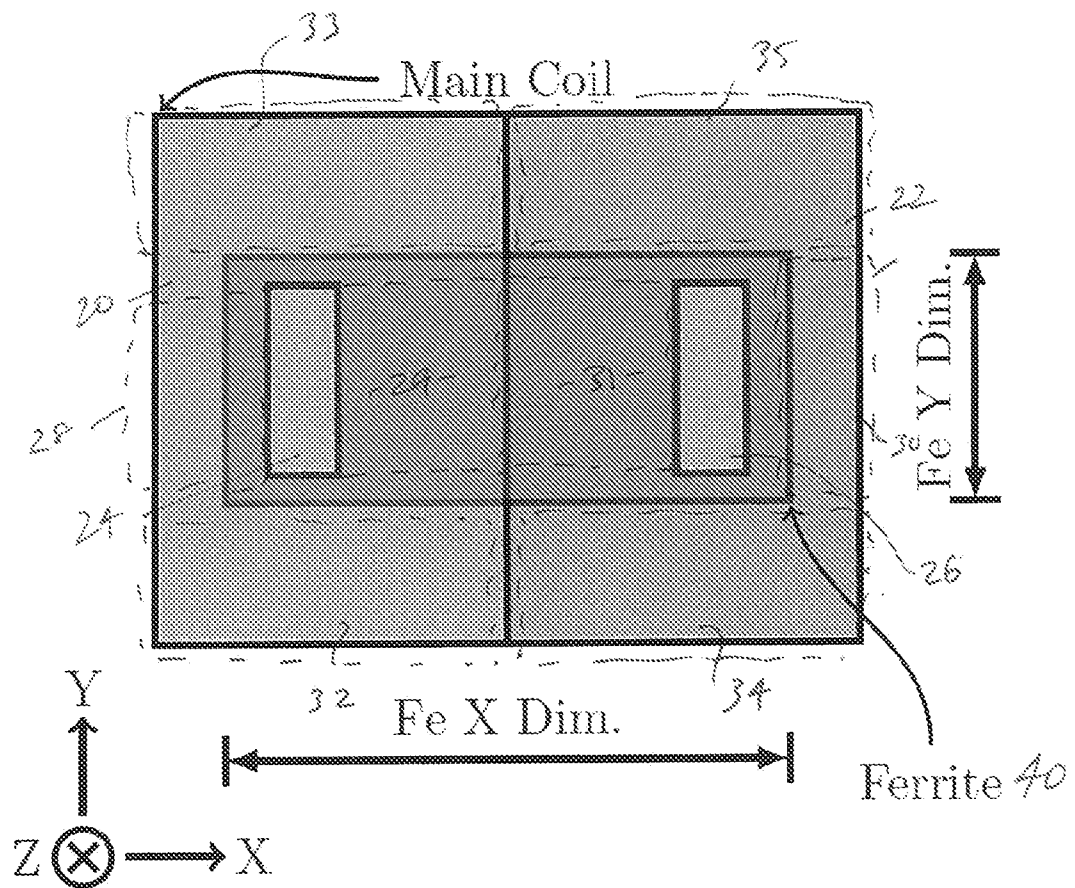


Figure 9

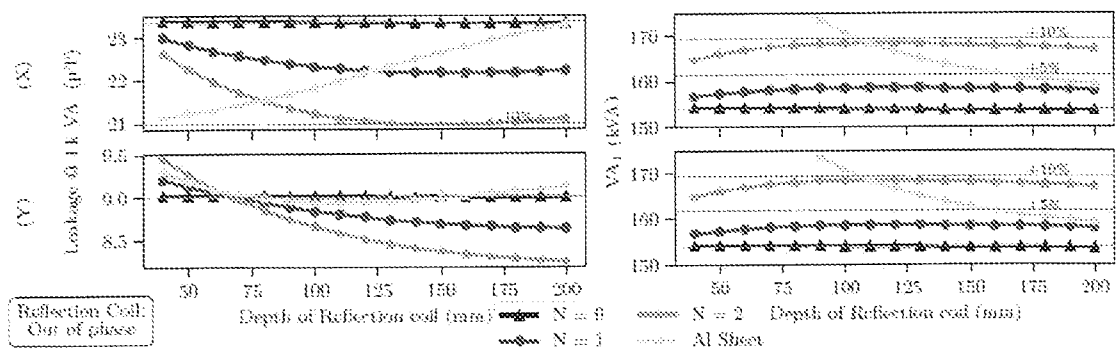


Figure 10

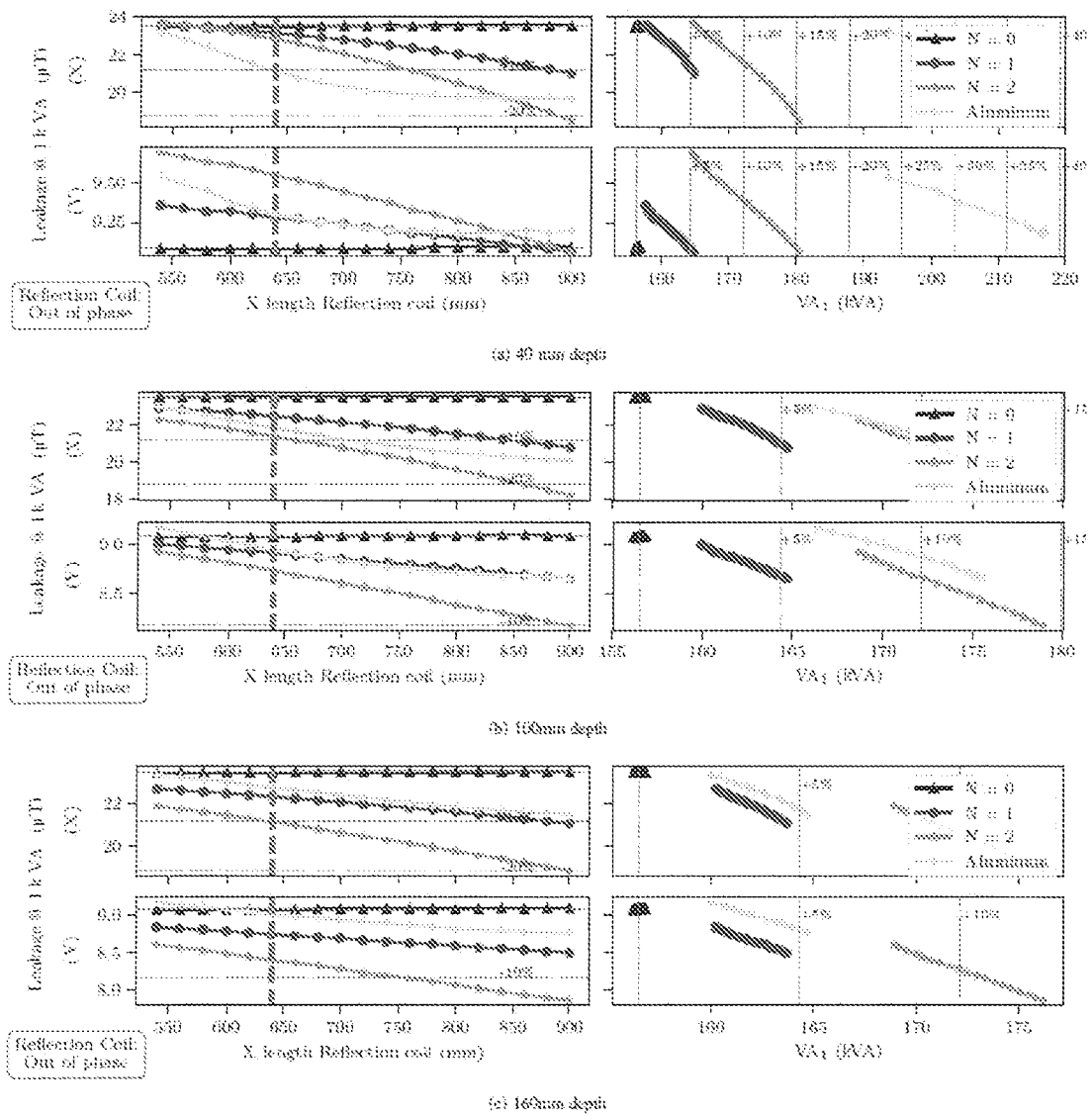
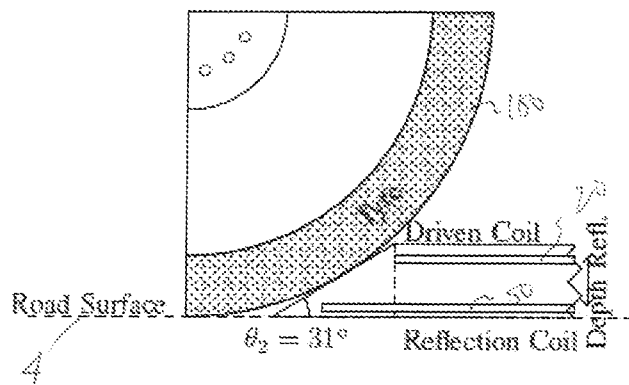


Fig. 10: Changing the size of the reflection coil in the X direction only, with ferrite dimensions of 250 x 100, and 3 different depths of the reflection coil: (a) 40 mm (b) 100 mm (c) 160 mm .

Figure 11



200 mm below top of driven coil

Fig. 11: Angle of blister

Figure 12

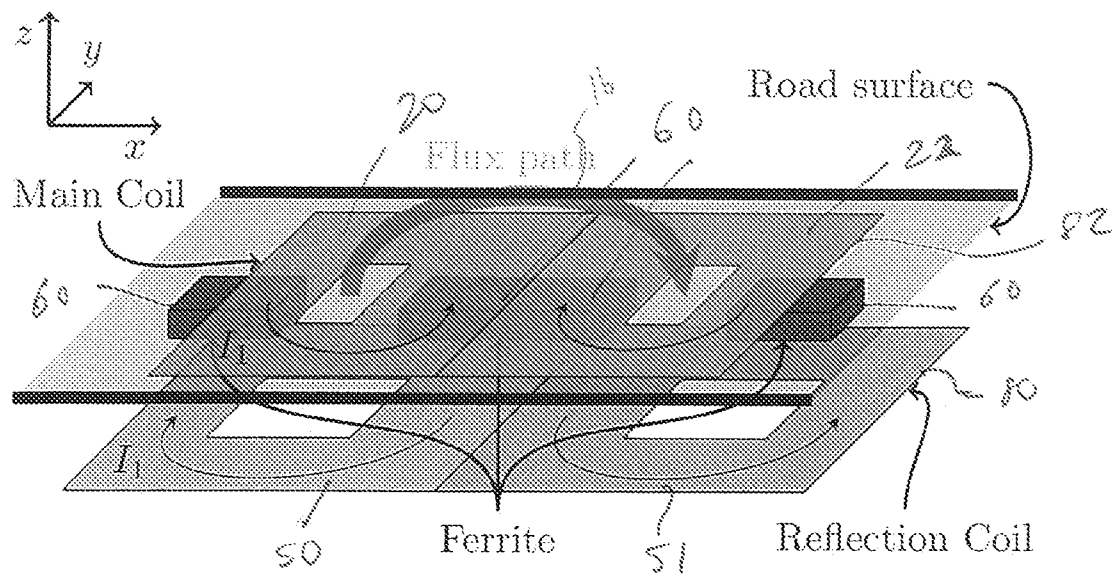
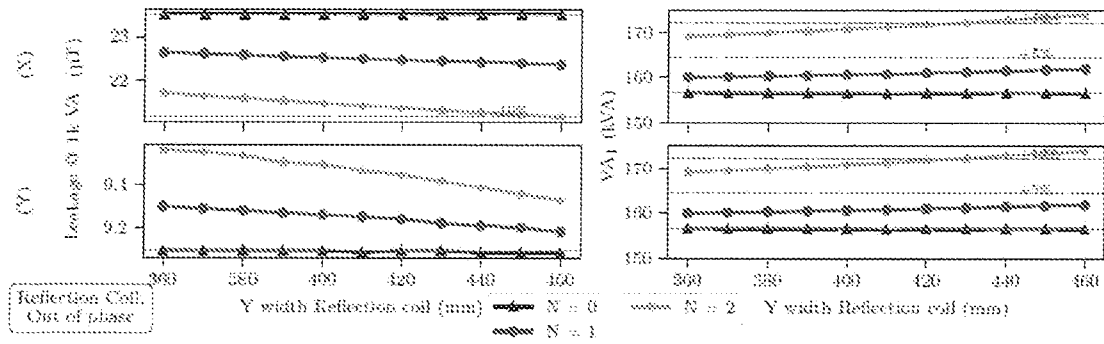


Figure 13



Reducing the size of the reflection coil in the Y dimension.

Figure 15

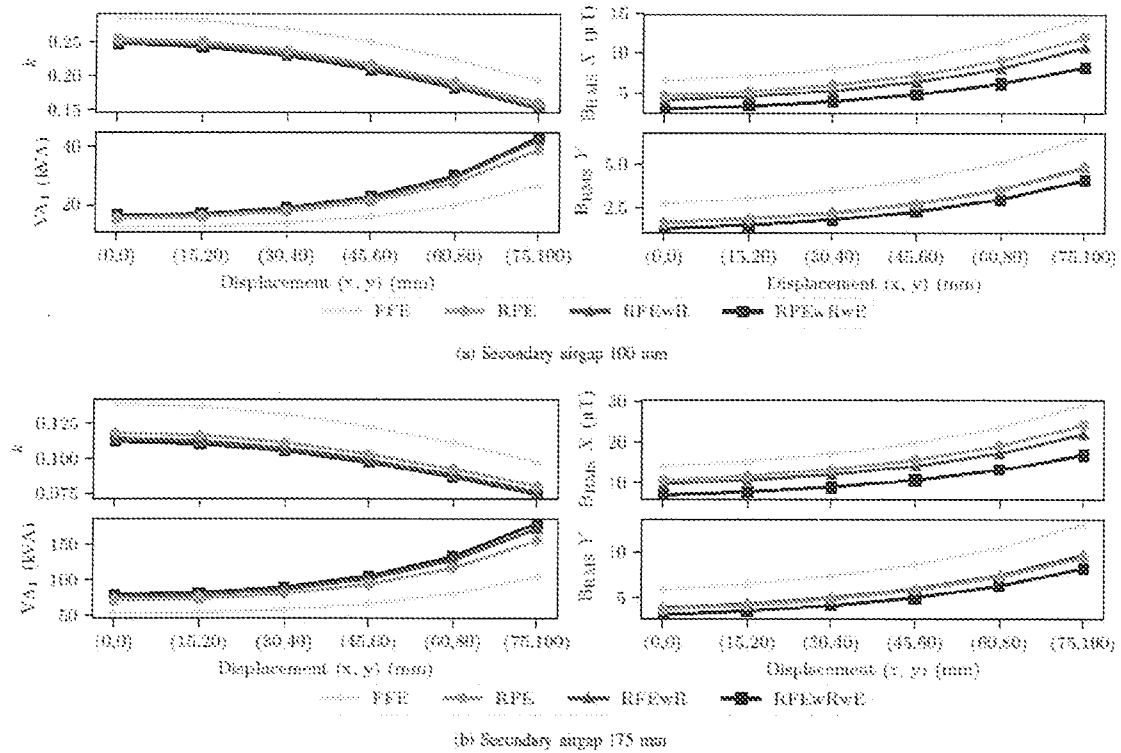


Figure 16

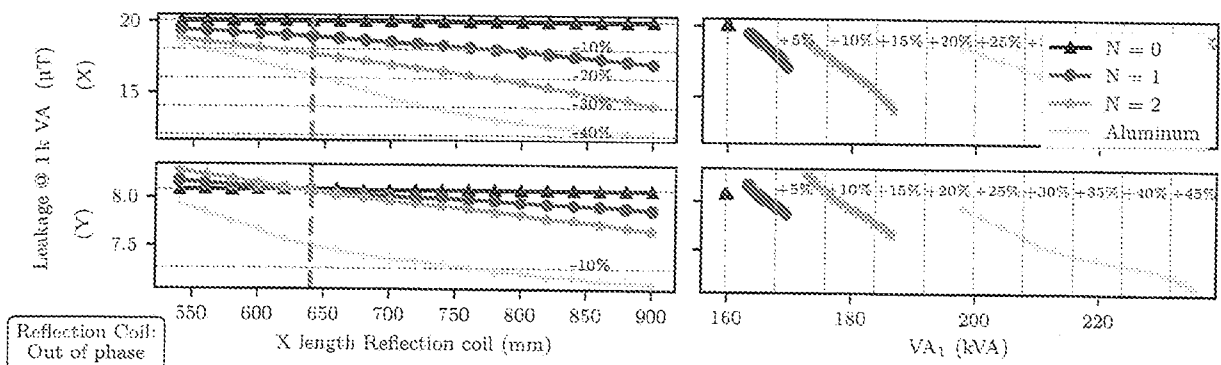


Fig. 17: With ferrite at the edge of the pad

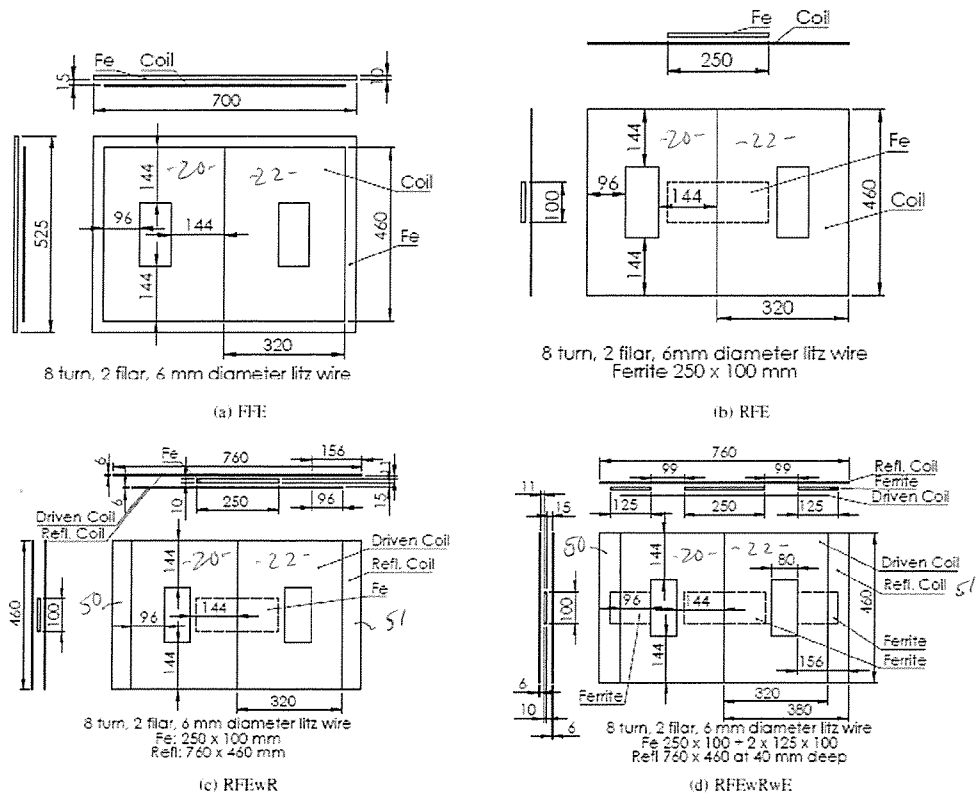
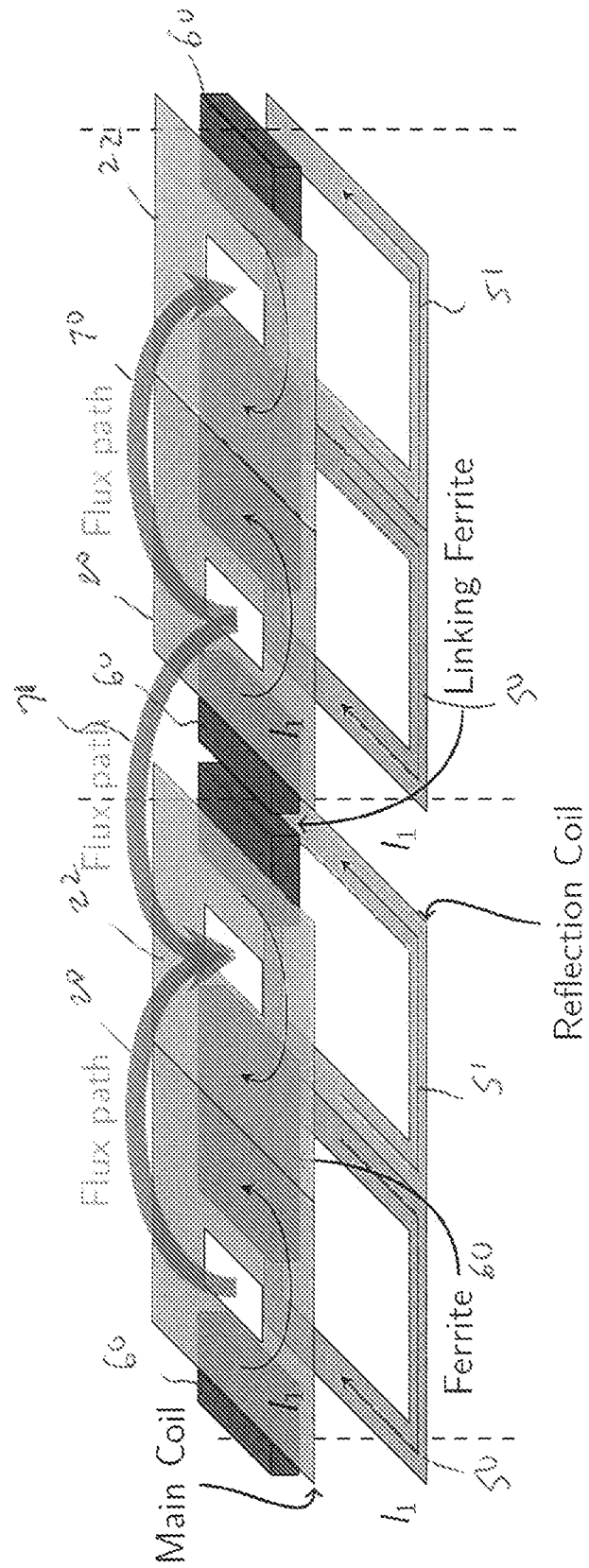


Figure 17: Dimensions of the pads discussed in this paper. (a) the base case ferrite pad (no aluminum or ferrite gap), (b) the reduced ferrite case, (c) the reduced ferrite with reflection coil, (d) the reduced ferrite with reflection coil and extended ferrite.

Figure 17

Adjacent Reduced Ferrite DD's



25

Split into Hybrid Square DD (for tracks) --- Square Mode

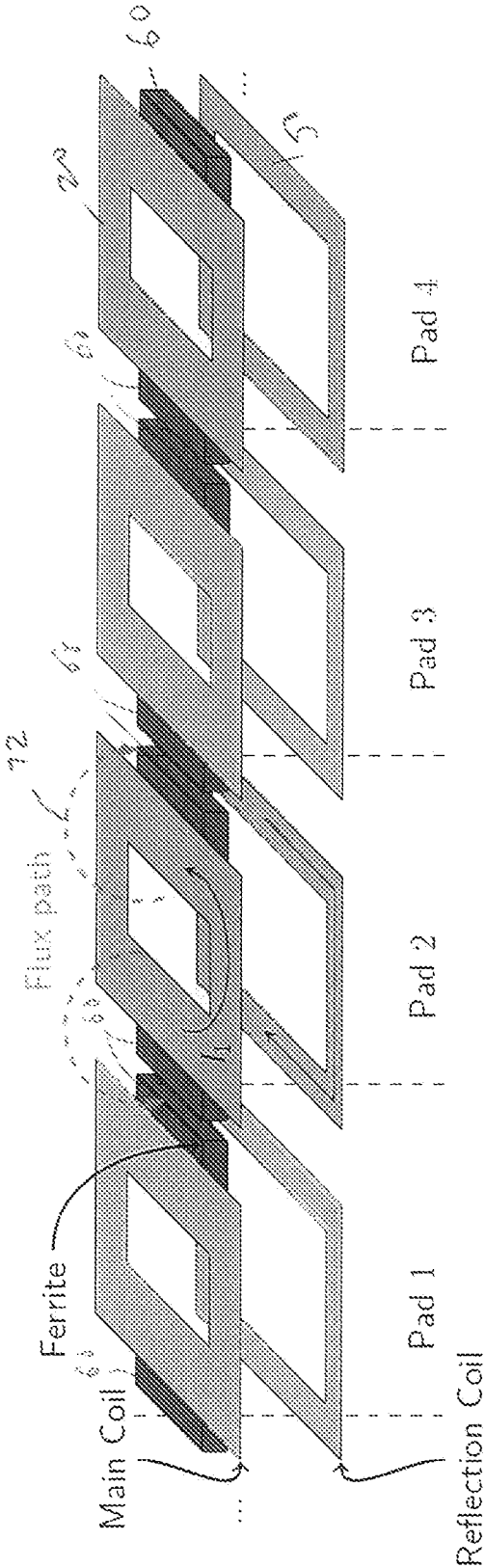


Fig 19

Split into Hybrid Square DD (for tracks) --- DD Mode

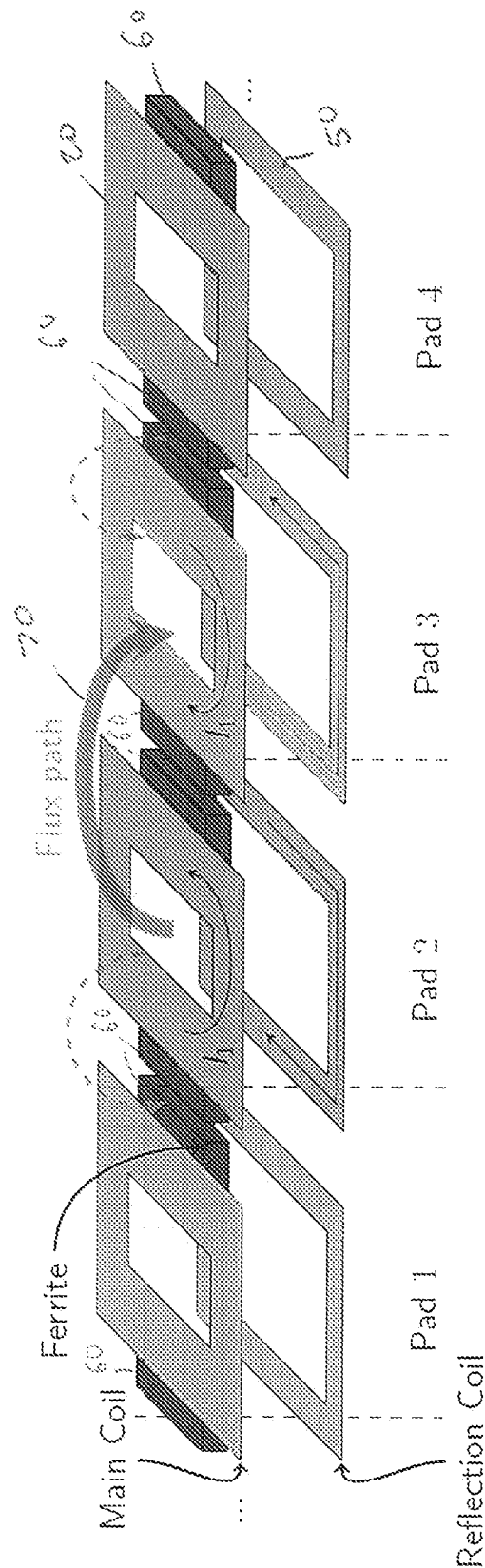


Fig 20

INTERNATIONAL SEARCH REPORT

 International application No.
PCT/IB2019/058274

A. CLASSIFICATION OF SUBJECT MATTER

B60L 53/10 (2019.01) B60L 53/38 (2019.01) H02J 50/70 (2016.01) H02J 50/10 (2016.01) H01F 27/34 (2006.01)

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)

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)

Databases: Espacenet, Google Patents and Google; CPC/IPC Symbols: H04B5/0037, H02J50/70, H02J50/10, B60L53/12, B60Y2200/91, Y02T90/122, H01H2047/046, B60L53/38, H01F27/346; keywords: reduced Ferrite DD with Reflection coil, RFDDwR road charging, reducing ferrite and roadway charging, electrified road for charging vehicles, leakage flux control "coil" layers road charging, eroad, wireless power transfer, vehicle, charging pads, roadway, DD layer, couple, ground, vehicle, primary coil, leakage flux, reflection coil, ferrite block, magnetic, permeable material and like terms.

Applicant/Inventor names were searched in internal databases provided by IP Australia, Espacenet and AusPat.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	



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	"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
"D" document cited by the applicant in the international application	"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
"E" earlier application or patent but published on or after the international filing date	"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
"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)	"&" document member of the same patent family
"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	

Date of the actual completion of the international search 17 January 2020	Date of mailing of the international search report 17 January 2020
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA Email address: pct@ipaustalia.gov.au	Authorised officer Santosh Adhikari AUSTRALIAN PATENT OFFICE (ISO 9001 Quality Certified Service) Telephone No. +61262256169

INTERNATIONAL SEARCH REPORT		International application No.
C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		PCT/IB2019/058274
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2017/0366046 A1 (QUALCOMM INCORPORATED) 21 December 2017 see whole document, more specifically figs. 4-5, paras [0037-0046], [0052].	1-14
Y	US 2017/0222490 A1 (JOHN TALBOT BOYS et al.) 03 August 2017 see whole document, more specifically abstract, claim 1, figs. 4-5, 10, 27, paras [0003-0004], [0164], [0170], [0203-0208], [0223-0224], [0228], [0241], [0261].	1-14
A	QIU et al., "A Comparative Study of Flux Cancellation among Multiple Interconnected Modular Pads in Lumped IPT System", Progress In Electromagnetics Research M, Vol. 49, 131–140, January 2016. URL: https://www.researchgate.net/publication/308198650_A_comparative_study_of_flux_cancellation_among_multiple_interconnected_modular_pads_in_lumped_IPT_system see whole document	1-14
A	US 2015/0170833 A1 (QUALCOMM INCORPORATED) 18 June 2015 see whole document	1-14

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
the subject matter listed in Rule 39 on which, under Article 17(2)(a)(i), an international search is not required to be carried out, including
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

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

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

See Supplemental Box for Details

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

Remark on Protest

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

Supplemental Box**Continuation of: Box III**

This International Application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept.

This Authority has found that there are different inventions based on the following features that separate the claims into distinct groups:

Claims 1 to 11 & 13 to 14 (in part) define a wireless coupling apparatus comprising: a first layer comprising a flux coupling coil having two opposing end regions separated by two opposing side regions; a second layer comprising a first block of highly magnetically permeable material and a second block of highly magnetically permeable material; a third layer comprising a leakage flux control coil. It is considered that the feature of 'first block being provided proximate to one of the end regions and the second block being provided proximate to the other of the end regions' are specific to this set of claims.

Claims 12 & 13 to 14 (in part) define a wireless coupling apparatus comprising: a first layer comprising a flux coupling coil; a second layer comprising a highly magnetically permeable material & a third layer comprising a leakage flux control coil. It is considered that the feature relating to 'part of the periphery of the leakage flux control coil extending beyond a part of the periphery of the magnetically permeable material' is specific to this set of claims.

PCT Rule 13.2, first sentence, states that unity of invention is only fulfilled when there is a technical relationship among the claimed inventions involving one or more of the same or corresponding special technical features. PCT Rule 13.2, second sentence, defines a special technical feature as a feature which makes a contribution over the prior art.

When there is no special technical feature common to all the claimed inventions there is no unity of invention.

In the above groups of claims, the identified features may have the potential to make a contribution over the prior art but are not common to all the claimed inventions and therefore cannot provide the required technical relationship. Therefore there is no special technical feature common to all the claimed inventions and the requirements for unity of invention are consequently not satisfied *a priori*.

INTERNATIONAL SEARCH REPORT		International application No.	
Information on patent family members		PCT/IB2019/058274	
This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.			
Patent Document/s Cited in Search Report		Patent Family Member/s	
Publication Number	Publication Date	Publication Number	Publication Date
US 2017/0366046 A1	21 December 2017	None	
US 2017/0222490 A1	03 August 2017	US 2017222490 A1	03 Aug 2017
		CN 106716570 A	24 May 2017
		CN 107210126 A	26 Sep 2017
		EP 3167465 A1	17 May 2017
		EP 3192089 A2	19 Jul 2017
		JP 2017526170 A	07 Sep 2017
		JP 2017530562 A	12 Oct 2017
		KR 20170037613 A	04 Apr 2017
		US 2017214276 A1	27 Jul 2017
		WO 2016007023 A1	14 Jan 2016
		WO 2016039644 A2	17 Mar 2016
US 2015/0170833 A1	18 June 2015	US 2015170833 A1	18 Jun 2015
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Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.			