



(51) International Patent Classification:
H02J 7/00 (2006.01)

(21) International Application Number:
PCT/NZ2010/000160

(22) International Filing Date:
6 August 2010 (06.08.2010)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
16/273,701 7 August 2009 (07.08.2009) US

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM,

AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

- with international search report (Art. 21(3))
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

(54) Title: INDUCTIVE POWER TRANSFER SYSTEM

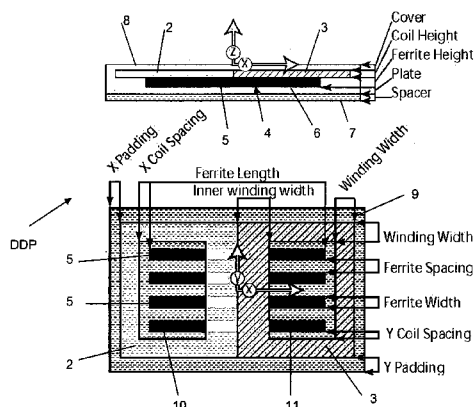


Figure 1: The DDP pad seen from the side (top) and from above (bottom).

(57) Abstract: A magnetic flux pad (BPP) is provided for generating or receiving magnetic flux. The pad may be used with an inductive power transfer system, and comprises a magnetically permeable core (4) and two substantially flat overlapping coils (2, 3) magnetically associated with the core (4). The coils (2, 3) are arranged so that there is essentially no mutual coupling between them.

INDUCTIVE POWER TRANSFER APPARATUS

Field of the Invention

- 5 This invention relates to apparatus for generating or receiving magnetic flux. The invention has particular, but not sole, application to a low profile, substantially flat device such as a pad for power transfer using an inductive power transfer (IPT) system.

Background

- 10 IPT systems, and the use of a pad which includes one or more windings which may comprise the primary or secondary windings for inductive power transfer, are reproduced in our published international patent application WO 2008/14033, the contents of which are incorporated herein by reference.
- 15 One particular application of IPT power transfer pads is electric vehicle charging, and that application is discussed in this section to provide the background to one application of the invention. However, electric vehicle charging is an example of only one application, and the invention has application to inductive power transfer in general. Electric vehicle charging may
- 20 occur while the vehicle is stationary, or alternatively while the vehicle is moving along a roadway, for example. IPT power transfer pads can be used both in the vehicle as a power "pickup" (i.e. the secondary side winding of the IPT system), and at a stationary location such as a garage floor or a roadway for example as the "charging pad" (i.e. the primary side winding) from which power is sourced.
- 25 The purpose of an IPT roadway system is to wirelessly transfer power to a stationary or moving vehicle without physical contact to the vehicle. The transmitting part of the system consists of a power supply supplying a lumped coil (for example a pad as described above) or a track with many similar lumped coils where such a system is tuned for operation at a suitable frequency,
- 30 usually anywhere from 10 kHz to 150 kHz. Where the receiver is placed underneath a vehicle and coupled to receive power either when the vehicle is stationary above or near (in sufficiently close proximity to couple power) to the primary transmitter. The pickup receiver also typically comprises a lumped coil (such as a pad described above) which is connected to a converter and appropriate controller within the vehicle to regulate power. For convenience, the part of a
- 35 roadway from which power may be received inductively is referred to herein as a track.

The track may be formed by placing a plurality of pads along the centre of a lane in a roadway. This results in the possibility of an essentially continuous supply of power to the vehicle as it moves along the roadway in the immediate vicinity of the track.

In recent years such systems have received increasing attention due to their potential to allow sustainable wireless powered personal transportation. For such a system to be useful it must not only be able to transfer sufficient power over an airgap of reasonable size (e.g. 100-300mm) it must also prove tolerant to any displacements between track and pickup, to avoid dependency on a vehicle-to-track guidance system. In a roadway system such displacement will most likely occur in the lateral direction (orthogonal to both vertical and the direction of movement) for moving vehicles. For stationary vehicle charging the ability to transfer acceptable levels of power with suitable longitudinal displacement is of particular concern in order to ensure ease of parking. The power transfer profile in the pick-up pad is ideally a smooth power profile which is essentially constant (and sufficient) over as wide as possible a distance laterally, with smooth drop-offs at each end. Such a power transfer profile eases the demands on the electronic (primary and secondary) regulators in the system, enabling improved operating performance for a comparable coupling over a system where during operation significant variations are experienced in the coupling between the primary and receiver pads.

Object of the Invention

It is an object of the present invention to provide apparatus for generating and/or receiving magnetic flux for the purposes of inductive power transfer, or to at least provide the public or the industry with a useful choice.

Summary of the Invention

In one aspect the invention broadly provides a magnetic flux pad for generating or receiving magnetic flux, the pad comprising a magnetically permeable core, two substantially flat overlapping coils magnetically associated with the core whereby there is substantially no mutual coupling between the coils.

Preferably the coils are substantially completely magnetically decoupled.

Preferably the coils partially overlap.

Preferably the coils are substantially coplanar.

Preferably the coils are provided on one side of the said permeable core, and a shielding means is provided on the other side of the core.

- 5 Preferably the shielding means comprises a shielding plate made of a suitable material such as aluminium.

Preferably a dielectric cover is provided on the side of the coils opposite the magnetic core.

- 10 Preferably the flux pad is adapted to receive currents from a power supply which are out of phase with each other to produce a time varying magnetic field which also varies spatially.

Preferably the field produced by the out-of-phase currents in the coils produces a time varying magnetic field which moves spatially and ultimately between the poles.

15

In a further aspect the invention provides primary power supply apparatus for an inductive power transfer system, the power supply apparatus including:

a magnetic flux pad for generating a magnetic flux, the pad comprising magnetically permeable core, two substantially flat overlapping coils magnetically associated with the

20

core; and
power supply adapted to provide a current in one coil which has a different phase to a current in the other coil.

- 25 Preferably the power supply is adapted to adjust the phase to produce a field that varies with time and with spatial position on the pad.

Preferably the apparatus includes means to detect where a field is or is not required in the vicinity of the pad and adjust the phase in response to an output of the sensing means.

- 30 Preferably the power supply includes an inverter for each coil.

Preferably the power supply comprises two inverters which are synchronised with each other to produce a current in one coil which is 90° out of phase with the current in the other coil.

- 35 Preferably the magnetic flux pad produces a sliding time varying magnetic field.

Alternatively, the power supply means operates the coils 180° out of phase with each other. In this embodiment one inverter may be used.

In a further aspect the invention broadly provides a method for providing an IPT magnetic flux pad having a plurality of coils in which there is no mutual magnetic coupling between the coils, the method including the steps of:

overlapping the coils

varying the overlap between the coils such that an overlap position is achieved whereby there is substantially no mutual coupling between the coils.

Preferably the absence of mutual coupling is detected by detecting when the open circuit voltage induced in one of the coils by energisation of the other coil is minimised.

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

Drawing Description

One or more embodiments of the invention will be described with reference to the accompanying drawings in which:

Figure 1 is a side view and a plan view respectively of a magnetic flux pad;

Figure 2: is a side view and plan view respectively of the pad of Figure 1 including a quadrature coil;

Figure 3: is a side view and plan view respectively of an alternative form of magnetic flux pad;

Figure 4: is a series of graphs of open circuit voltage coupled in one coil of the pad of the preceding figure as a function of overlap with the other coil when that other coil is energised;

Figure 5: shows graphs of uncompensated power against offset for a vertical space of 150 mm and 250 mm respectively;

Figure 6: is a graph of uncompensated power for three different flux pad constructions (according to Figure 3) with the receiver pad offset either in the x or y direction at a vertical separation of 200 mm;

5 Figure 7: illustrates field plots for the pad construction of Figure 3 and Figure 1 respectively at various instances of time over a full cycle of primary resonant current;

Figure 8: shows the field plot of the pad construction of Figure 3 with an increasing amount of ferrite in the core (from the top to the bottom direction);

10

Figure 9: shows a graph of an example of a power transfer profile of a pad construction according to that shown in Figure 3 with a receiver pad that accords with that shown in the example of Figure 2.

15 Description of One or More Preferred Embodiments

Referring to Figure 1, a magnetic flux pad construction is shown. For convenience, this general construction is referred to herein as a DDP pad, and is generally referenced DDP in the relevant drawing figures.

20

The DDP pad shown in Figure 1 generally comprises two substantially coplanar coils referenced 2 and 3 which are magnetically associated with and sit on top of, a core 4. As can be seen from the drawing figure, the core 4 may consist of a plurality of individual lengths of permeable material such as ferrite strips or bars 5 which are arranged parallel to each other but spaced
25 apart. The pad construction may include a spacer 6 on which the core is located, and a plate 7 below the spacer. In some embodiments a cover 8 may be provided on the other surface of the flat coils 2 and 3. Padding 9 may be provided about the periphery of the pad. As can be seen, the coils 2 and 3 each define a pole area 10 and 11 respectively. This DDP pad construction as shown in Figure 1 shows very good characteristics suitable for IPT power transfer applications
30 such as vehicle charging. The coils 2, 3 may be connected out of phase and driven by a single inverter to produce a stationary time varying magnetic field to couple to a receiver (which may for example be of substantially the same magnetic design) at distances suitable for electric vehicle power transfer with good coupling.

35 Turning now to Figure 2, the DDP construction of Figure 1 is shown but further including a quadrature coil 12 (referred to herein as a DDPQ pad). The quadrature coil extends the power

transfer profile when there is lateral movement of the construction shown in Figure 2 with respect to a flux generator such as the DDP pad of Figure 1 when energised by an appropriate inverter. The quadrature coil allows power to be extracted from the "vertical" component of the magnetic field that the receiver pad intercepts while the other coils 2, 3 facilitate power
5 extraction from the "horizontal" component of the flux intercepted. Therefore, the construction of Figure 2 is suited as a flux receiver.

Turning now to Figure 3, another construction is shown which is referred to in this document as a bi-polar pad or, alternatively, as a BPP pad. The BPP pad has a similar construction to the
10 DDP pad discussed with respect to Figures 1 and 2 above as it enables excellent coupling to secondary receivers at distances suitable for charging and powering of electric vehicles.

The pad BPP consists, from bottom up, of an aluminium plate 7, a dielectric spacer 6, a core 4 comprising four rows of ferrite bars 5 (referred to herein as ferrites), two flat substantially
15 coplanar, yet overlapping and ideally "rectangular" shaped coils 2, 3 (although in practice these are more oval due to the ease in winding Litz wire) spread out in the lateral direction, and a dielectric cover 8. The core 4 acts as a shield so that ideally all flux is directed away from the core 4 through the top of the pad. The plate 7 merely acts to a) eliminate and small stray or spurious fields that may be present beneath the core 4 in certain environments, and b) provide
20 additional structural strength. The BPP is shown in Figure 3, and Table A1 defines the actual dimensions investigated in simulation and for one experimental prototype.

The magnetic structure of the BPP is designed so that there is substantially no mutual coupling between either of the coils 2, 3 in the primary, as described later. This allows the coils to be
25 driven independently at any magnitude or phase without coupling voltage into each other which if present would oppose the power output of such a coil.

In one mode of operation, the two coils within the BPP can be driven using two separate but synchronised inverters operating with known current magnitude and phase difference. If the
30 coils are completely magnetically decoupled ideally there will be no power transfer between the primary inverters to limit power transfer to the secondary receiver.

In one embodiment the two inverters are synchronised but operated so as to produce currents with the same RMS magnitude, but operating 90 degrees out of phase in each of the coils 2, 3.
35 (In a stationary application this would likely be two H bridge inverters with LCL structures tuned to resonance at the desired operating frequency the last L in each case being partially

constructed using the pad inductance, where the primary inverters preferably have a common DC bus to simplify the input electronics from the mains. By having a 90° phase separation between the currents in the coils 2, 3, a spatially varying and time varying magnetic field is created rather than the stationary time varying magnetic field of the DDP. This is shown in Figure 7 in which the left column represents a DDP pad and the right column represents a BPP pad. The spatial variation in the field of the BPP and appears as a sliding movement in alternate directions between the poles of the coils 2, 3.

It should be noted that other relative phase and/or magnitude variations between the currents in the coils could be used to shape the field if there is a need to reduce the field emissions on one side of the transmitter to avoid leakage during operation due to offset nature of the coupled receiver, for example to meet ICNIRP regulations. Thus the field may be directed in response to the output of a sensor for example which may sense where greater field strength is required, or where the field strength should be reduced. Also, the field strength may be time varying but spatially stationary dependent on where across the pad the field is required.

In a further embodiment it is also possible to operate the coils 2, 3 180 degrees out of phase so that they can be simply connected to one inverter (as in the DDP operation). This particular single phase operating mode is a second possible mode of operation to simplify the electronic control and power conversion that will produce a stationary time varying field as for the DDP.

As a means of comparison, the power transfer profile of a BPP with a sliding time varying magnetic field is evaluated against the power transfer profile of a DDP magnetic structure driven from a single phase primary supply at identical current and frequency (the dimensions of which are defined in Tables A2.). Both systems are evaluated under identical conditions being coupled to an identical DDQP receiver (i.e. a DDP pad including a quadrature coil such as that of Figure 2 used as a flux receiver) at identical height and offsets (the dimensions of which are defined in Table A3).

Given the BPP creates what may be termed a sliding time varying magnetic field it is desirable to determine the preferred length of the four ferrite strips used in its base above which the coils 2, 3 are placed. As in the known DDP these ferrite strips are used to enhance the power transfer and ensure that a predominately single sided flux field is created to best couple to the secondary power receiver, while ensuring that a minimal amount of ferrite is used to keep weight to a minimum and restrict the inductance of the pad. In such a sliding field it is shown that the ferrite strips should preferably extend under the winding coils otherwise the field may

not be forced upwards towards the receiver.

In this evaluation the ferrite strips 5 were constructed using readily available slabs that are each a standard length of 93 mm. Each strip was conveniently chosen to be multiples of this length.

5 Configurations with six (558 mm), eight (744 mm) and ten (930 mm) slabs lumped together were investigated. In all designs (apart from the 10 slab ferrite configuration) the external dimensions of the pad size of the BPP are identical to the DDP enabling a fair comparison. The ten piece ferrite configuration however forces the overall length (in the x direction) of the transmitter (or generator) pad to be increased beyond the standard length by 200 mm
10 (compared to all other pads including the DDP configurations compared) and therefore is only included in evaluations to consider the impact of extensions to the ferrite beyond the coil dimensions. As indicated in Table A1 the distance between the ends of the two coils in all three BPP setups is identical although the overlap between the coils is set to that required to avoid mutual coupling arising between the primary coils.

15 When the two primary coils 2, 3 of the BPP are placed with an arbitrary overlap with respect to each other, there will be a mutual coupling between the coils. However for a certain ratio of overlap to coil width, denoted r_o , this mutual coupling is almost zero. The ideal overlap required to ensure no mutual coupling exists between each primary coil is not simple due the presence of
20 the ferrite but can be determined by simply fixing one coil and energising this with a predetermined current at fixed frequency (either via a suitable 3D simulator or using a suitable experimental setup, for example). The open circuit voltage induced in the second primary coil can then be measured. If the second coil is moved so as to change the overlap there will be a change in coupled voltage. When this is minimised (ideally zero) the ideal configuration can be
25 set. As shown in Figure 4, the optimal overlap is dependent on the length of the ferrite strips underneath the coils. For the six, eight and ten piece ferrite pad the overlapping ratio, r_o was found to be 0.53, 0.34 and 0.25 respectively.

The finite element solver JMAG Studio™ version 10.0 was used to simulate all proposed
30 magnetic structures. Validation of the simulator outputs was confirmed by constructing a prototype BPP in the laboratory using ferrite strips comprised of 6 ferrite slabs in the base and compared against simulations. This scaled model used the external dimensions of table A1 for the BPP but simplified coils with only 10 turns each to simplify the construction. The receiver was a DDQP as described in table A3. The comparison between measurement and simulation
35 of Figure 5 shows excellent correlation.

The power profiles given here are the total uncompensated VA power output which is determined using separate measurements of the receiver open circuit voltage (V_{oc}) and short circuit current (I_{sc}). The uncompensated VA is a well known measure of the power performance of a pad given by $S_u = V_{oc} * I_{sc}$. The DDQP receiver has two sets of coils, the coils 2, 3 (assuming they are in series) and the quadrature (Q) coil 12. In this case the uncompensated power is found for both sets of coils separately and the total uncompensated power available from the pickup is referred to as the total power which is simply calculated as the sum of the power from the two sets of coils. It is this total power which underlies the power transfer profile.

The power transfer profile of each BPP design can therefore be confidently determined using 3D simulation and is shown in Figure 6. Here the BPP is excited with a 20kHz current with 23A rms while the receiver is the DDQP. The parameters governing their relative position are referred to as the offset distances, in Cartesian coordinates, that is: x_{os} (lateral), y_{os} (longitudinal) and z_{os} (vertical). The configuration of the two pads lying on top of each other with their dielectric covers 8 touching is (0,0,0). The vertical offset z_{os} is 200 mm.

Notably there is a significant increase in power when the ferrite under the coils is extended, and it is clear that the ferrite should extend at least under the entire coil 2, 3 (BPP with 8 ferrite slabs). The reason for the drastic increase in uncompensated power from the BPP as ferrite is added to its base, lies in the non-stationary nature of its magnetic field. The field close to the BPP pad can best be described as a sliding wave across the surface, unlike the DDP which pulsates up and down due to its single phase nature. This sliding nature, and fundamental difference, between the BPP and the single phased DDP, is clearly evident in Figure 7, where the magnetic flux density is compared phase by phase for half a period. In Figure 7 field plots of both the BPP8 and DDP coupling to a DDQP receiver are shown, at various instances in time over a full cycle of the primary resonant current. From top to bottom shows 0, 30, 60, 90, 120 and 150 degrees (where in the bipolar the other phase is operated with 90 degree separation). The plots in the left column are for a BPP pad with 8 ferrite slabs. The plots in the right column are for a DDP pad. The flux from the single phase DDP pad pulsates up and down, having a very strong and confined flux centred over the pad, whereas the BPP has a more constant flux pattern-wise, but this pattern shifts over the surface of the pad like a sliding wave as the phase advances.

The sliding wave of the BPP gives rise to very localised high flux on the edge of pad, whereas the DDP pad keeps the strong flux in the centre of the pad. In the six piece version there is no ferrite under the ends of the coils, and the flux is not contained well enough by the dielectric

filling material 6 (wood). It is therefore not radiated upwards, but rather inducing eddy currents in the aluminium base plate 7 of the pad. In Figure 8 the three setups are compared for the same phase. Figure 8 shows field plots for a BPP pad with six (top), eight (middle) and ten (bottom) slabs making up each ferrite strip in the base, in the presence of a vertical offset DDQP receiver at 0 degrees. The flux density appears qualitatively different, especially around the right edge where the flux density is high for the eight and ten ferrite setups, but not for the six ferrite setup. In the ten ferrite version, the flux is even better confined, with less of the field "wrapping around" the side of the track pad, again a factor responsible for decreasing the power transfer, since the field will not be pushed towards the pickup (i.e. the receiver pad) as desired.

The BPP with the eight ferrite slabs in each ferrite base strip (BPP8) is compared to the DDP in Figure 9. The power transfer profile of the BPP8 compared against the profile of the DDP reveals the very evident differences in shape and maximum. As configured, the BPP8 yields around 70% of the DDP's maximum power and has similar power profile shapes. The power levels shown and coupling achieved is however sufficient to deliver suitable levels of power to an electric vehicle for example, at distances required for practical application and furthermore do not exhibit as significant a rate of change of variation of power around the peak with offset as that seen in the DDP power profile. This limited rate of change of power is an advantage when considering power highway applications given there will not be severe fluctuations in power with lateral movement.

Table A1: Dimensions of the BPP

Common Dimensions

Winding width	80 mm
Ferrite spacing	32 mm
Ferrite width	28 mm
Y coil spacing	50 mm
Y padding	46 mm
Cover thickness	6 mm
Coil height	4 mm
Ferrite height	16 mm
Spacer thickness	6 mm
Plate thickness	4 mm

Variations based on number of ferrites

A: BPP6: using 6 ferrite slabs to make each ferrite strip

(BPP6) Ferrite length	558 mm
(BPP6) Overlap	156 mm

X coil spacing	10 mm
X padding	10 mm

B: BPP8: using 8 ferrite slabs to make each ferrite strip
 Ferrite length 774 mm

	Overlap	74 mm
	X coil spacing	– 83 mm (– represents an overlap)
	X padding	10 mm
5	C: BBP10: using 10 ferrite slabs to make each ferrite strip	
	Ferrite length	930 mm
	Overlap	39 mm
	X coil spacing	–174 mm (– represents an overlap)
10	X padding	110 mm (nb: 200mm added overall to padding to fit extra ferrites)

Table A2: Dimensions of the DDP

15	Winding width	80 mm
	Inner winding width	120mm
	Ferrite spacing	32 mm
	Ferrite width	28 mm
	Y coil spacing	10 mm
20	Y padding	46 mm
	Cover thickness	6 mm
	Coil height	4 mm
	Ferrite height	16 mm
	Spacer thickness	6 mm
25	Plate thickness	4 mm
	Ferrite length	558 mm
	X coil spacing	10 mm
	X padding	10 mm

30

Table A3: Dimensions of the DDQP

	Winding width	80 mm
	Inner winding width	120mm
35	Ferrite spacing	32 mm
	Ferrite width	28 mm
	Y coil spacing	10 mm
	Y padding	46 mm
	Cover thickness	6 mm
40	Coil height	4 mm
	Ferrite height	16 mm
	Spacer thickness	6 mm
	Plate thickness	4 mm
	Ferrite length	558 mm
45	X coil spacing	10 mm
	X padding	10 mm
	Quadrature coil length	534 mm

50

Where in the foregoing description, 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.

- 5 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 or spirit of the invention.

Claims

1. A magnetic flux pad for generating or receiving magnetic flux, the pad comprising a
5 magnetically permeable core, two substantially flat overlapping coils magnetically associated with the core whereby there is substantially no mutual coupling between the coils.
2. A magnetic flux pad as claimed in claim 1 wherein the coils are substantially completely magnetically decoupled.
- 10 3. A magnetic flux pad as claimed in claim 1 or claim 2 wherein the coils partially overlap.
4. A magnetic flux pad as claimed in any one of the preceding claims wherein the coils are substantially coplanar.
- 15 5. A magnetic flux pad as claimed in any one of the preceding claims wherein the coils are provided on one side of the permeable core, and a shielding means is provided on the other side of the core.
- 20 6. A magnetic flux pad as claimed in claim 5 wherein the shielding means comprises a shielding plate made of a suitable material such as aluminium.
7. A magnetic flux pad as claimed in any one of the preceding claims wherein a dielectric cover is provided on the side of the coils opposite the magnetic core.
- 25 8. A magnetic flux pad as claimed in any one of the preceding claims wherein the flux pad is adapted to receive currents from a power supply which are out of phase with each other to produce a time varying magnetic field which also varies spatially.
- 30 9. A magnetic flux pad as claimed in claim 8 wherein the field produced by the out-of-phase currents in the coils produces a time varying magnetic field which moves spatially and alternately between the poles.
- 35 10. Power supply apparatus for an inductive power transfer system, the power supply apparatus including:
a magnetic flux pad for generating a magnetic flux, the pad comprising a magnetically permeable core, two substantially flat overlapping coils magnetically associated with the

core; and

a power supply adapted to provide a current in one coil which has a different phase to a current in the other coil.

- 5 11. Power supply apparatus as claimed in claim 10 wherein the power supply is adapted to adjust the phase to produce a field that varies with time and with spatial position on the pad.
12. Power supply apparatus as claimed in claim 10 or claim 11 including means to detect where a field is or is not required in the vicinity of the pad and adjust the relative phase and/or
10 amplitude of the current in the coils in response to an output of a sensing means.
13. Power supply apparatus as claimed in any one of claims 10 to 12 wherein the power supply includes an inverter for each coil.
- 15 14. Power supply apparatus as claimed in any one of claims 10 to 13 wherein the power supply comprises two inverters which are synchronised with each other to produce a current in one coil which is 90° out of phase with the current in the other coil.
15. Power supply apparatus as claimed in any one of claims 10 to 14 wherein the magnetic
20 flux pad produces a sliding time varying magnetic field.
16. Power supply apparatus as claimed in any one of claims 10 to 12 wherein the power supply operates the coils 180° out of phase with each other.
- 25 17. Power supply apparatus as claimed in claim 16 wherein the power supply includes one inverter for energising both coils.
18. A method for providing an IPT magnetic flux pad having a plurality of coils in which there is no mutual magnetic coupling between the coils, the method including the steps of:
30 overlapping the coils, and
varying the overlap between the coils such that an overlap position is achieved whereby there is substantially no mutual coupling between the coils.
- 35 19. A method as claimed in claim 18 wherein the absence of mutual coupling is detected by detecting when the open circuit voltage induced in one of the coils by energisation of the other

coil is minimised.

20. A magnetic flux pad substantially as herein described with reference to any embodiment shown in the accompanying drawings.

5

21. Power supply apparatus for an inductive power transfer system substantially as herein described with reference to any embodiment shown in the accompanying drawings.

10 22. A method for providing an IPT magnetic flux pad having a plurality of coils in which there is no mutual magnetic coupling between the coils substantially as herein described.

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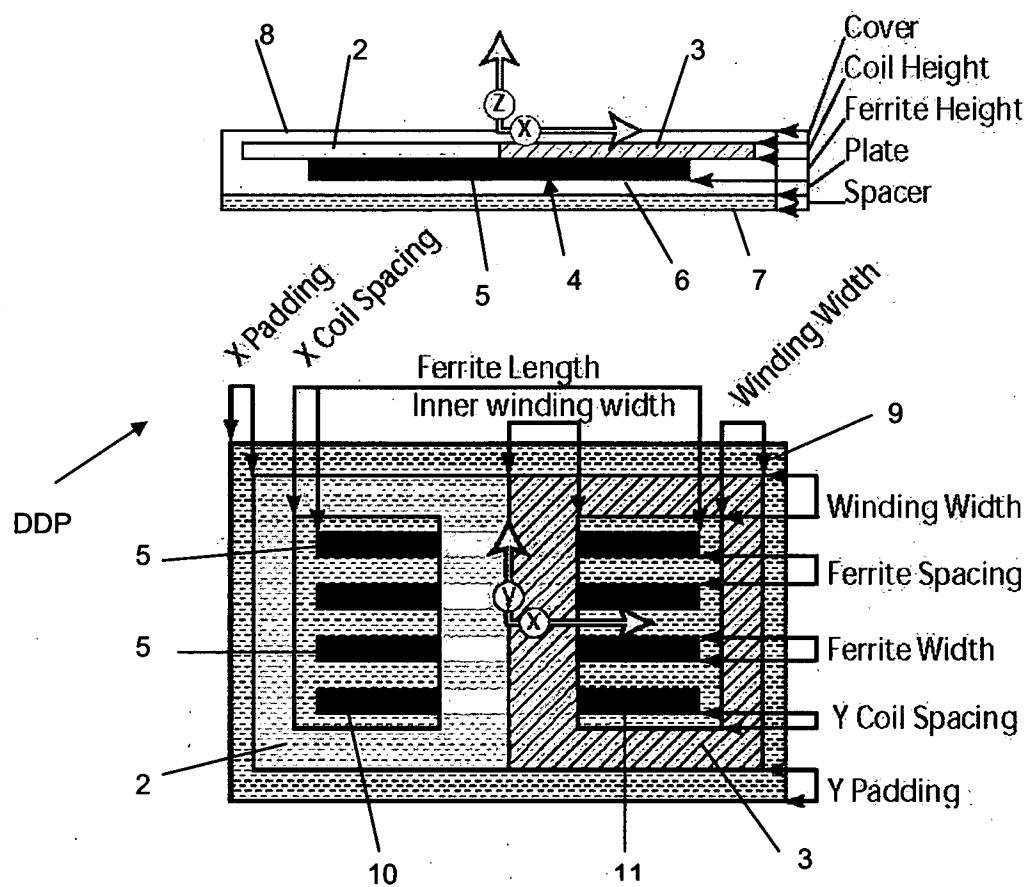


Figure 1: The DDP pad seen from the side (top) and from above (bottom).

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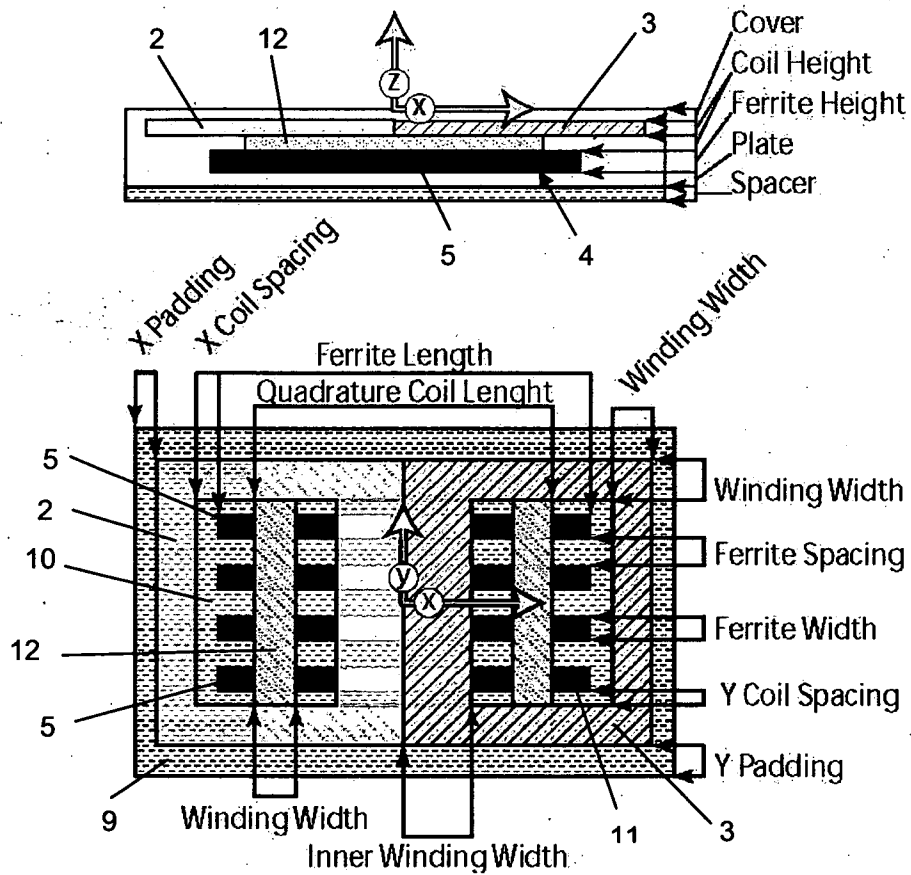


Figure 2: The double D quadrature pad seen from the side (top) and from above (bottom).

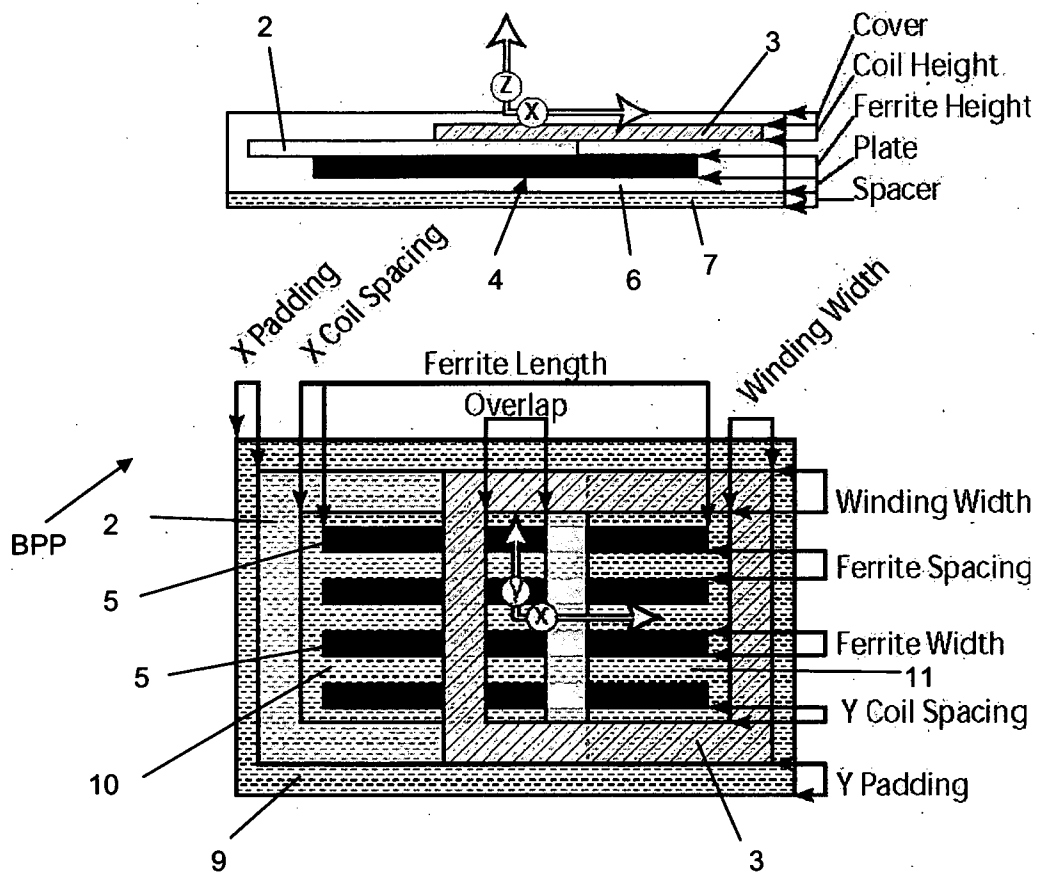


Figure 3: The bipolar pad seen from the side (top) and from above (bottom).

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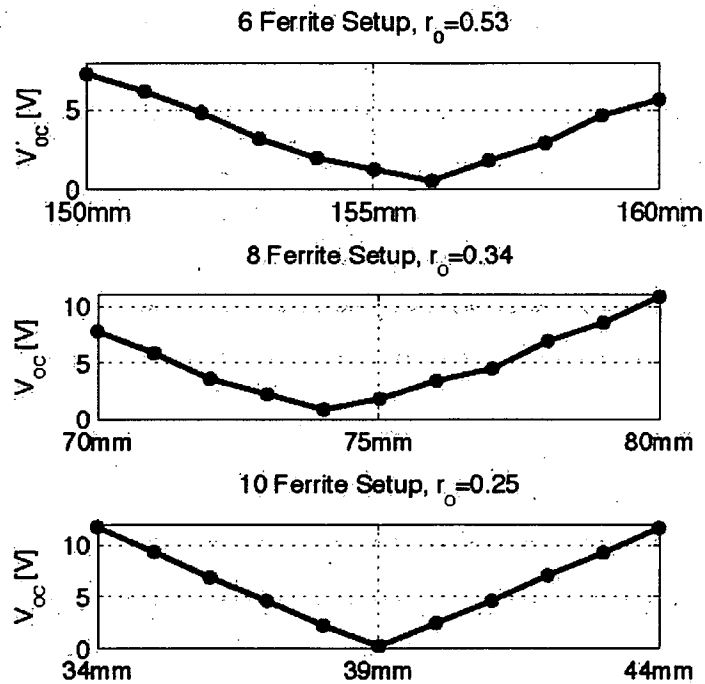


Figure 4: Open circuit voltage coupled in the second BPP coil as a function of overlap when the first coil is energised.

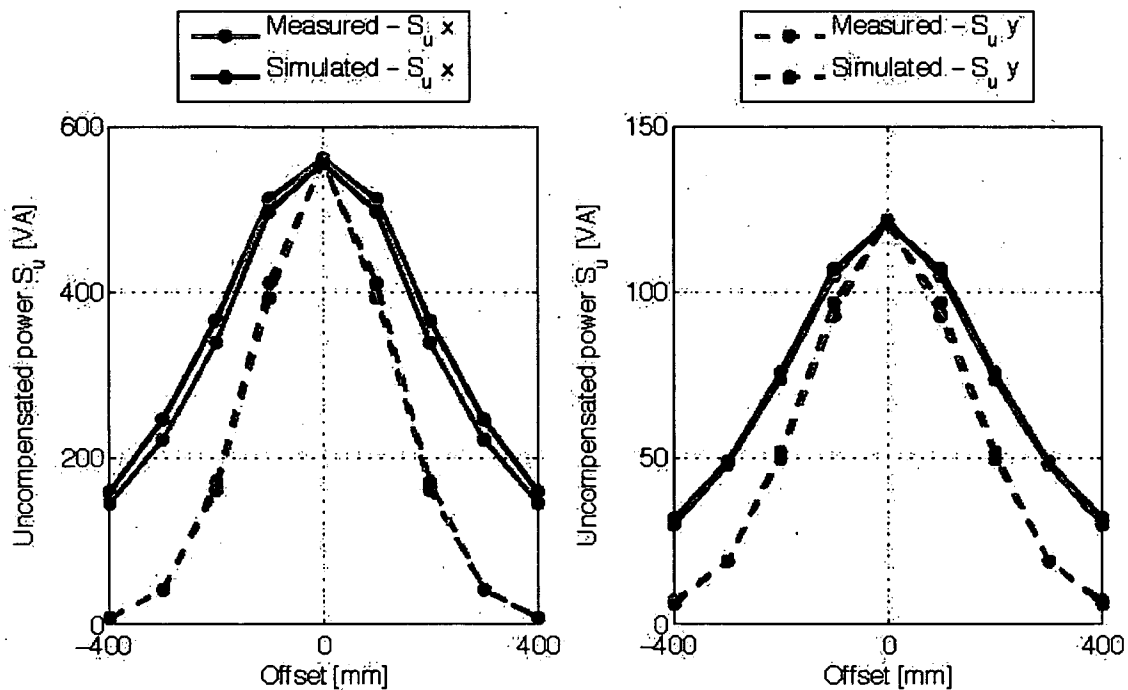


Figure 5: Measured and simulated power of a BPP with ten turns in each coil using six ferrite slabs to construct each of the ferrite strips in the base: Vertical displacements are 150 mm in the left column, and 250 mm in the right column.

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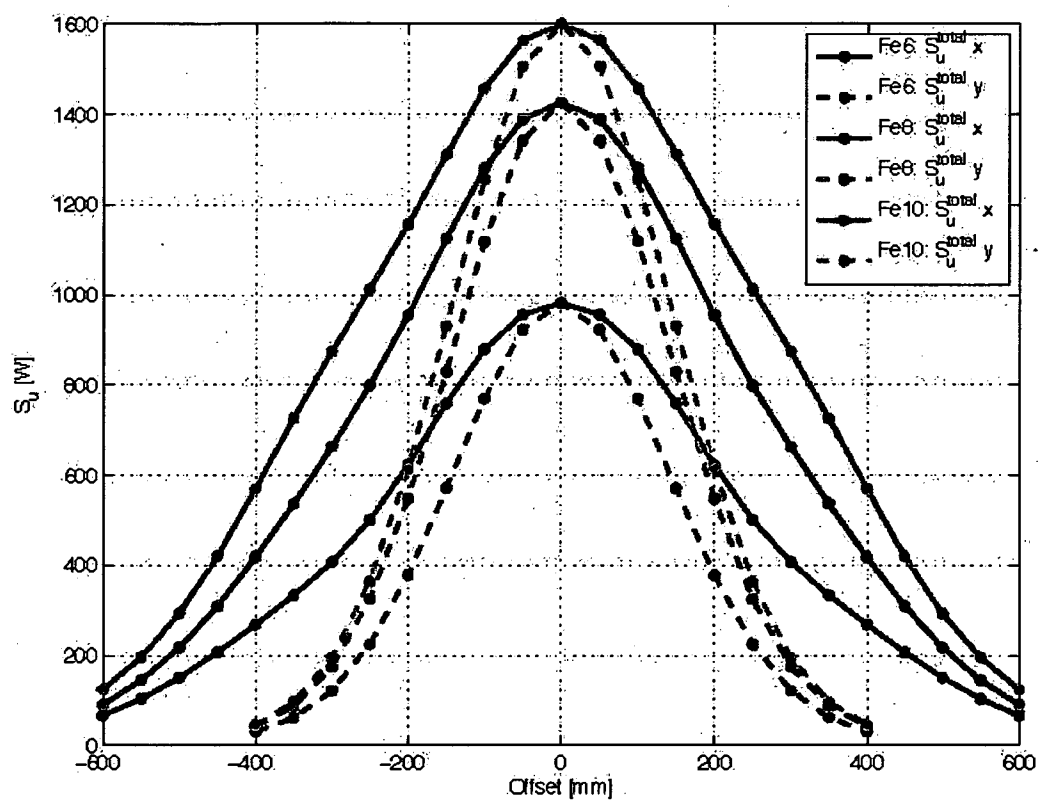


Figure 6: Uncompensated power for the three BPP setups with the pickup offset either in the x or y direction at 200 mm vertical separation

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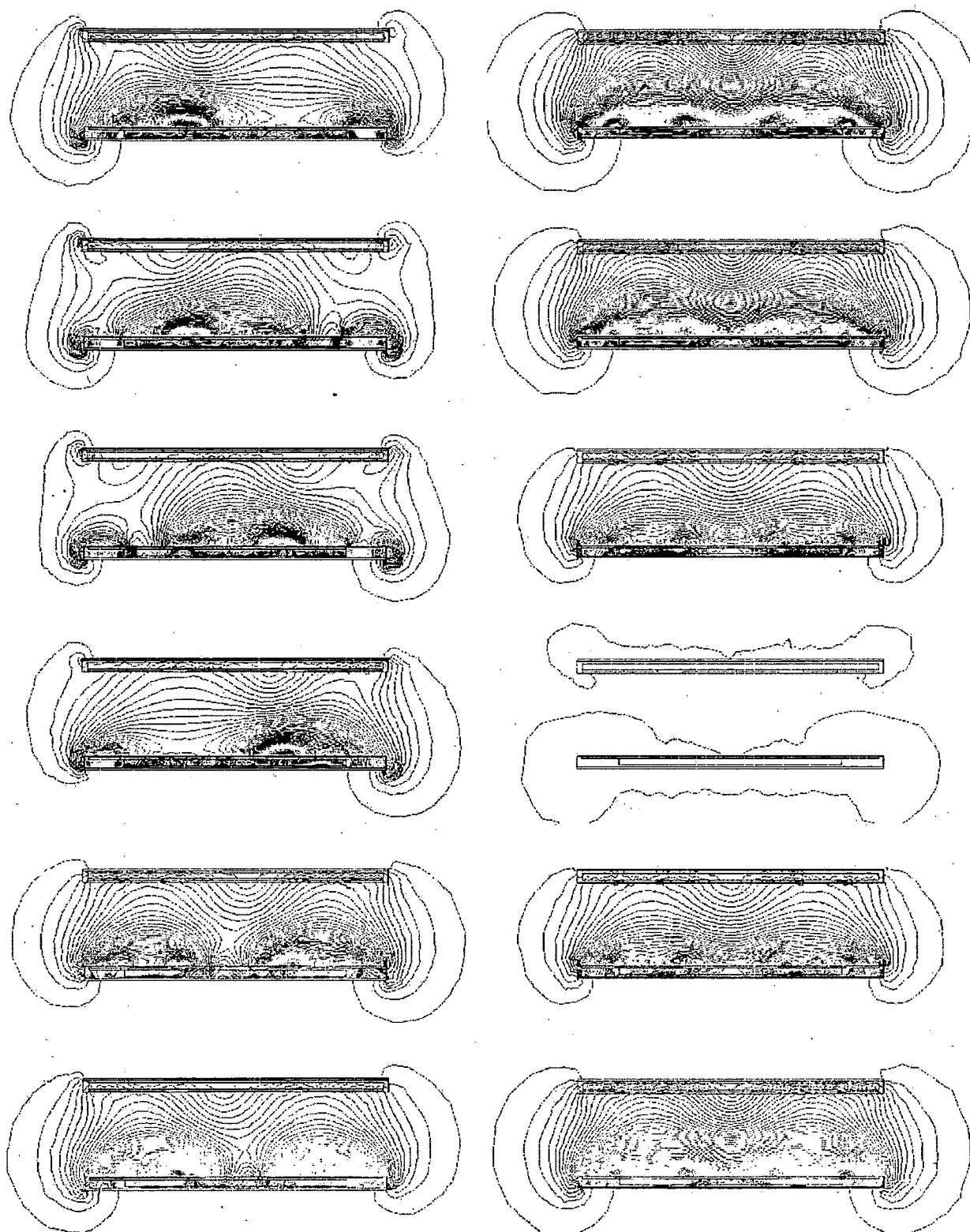


Figure 7: Field plots of both the BPP8 and DDP coupling to a DDQP receiver, at various instances in time over a full cycle of the primary resonant current. From top to bottom shows 0, 30, 60, 90, 120 and 150 degrees (where in the bipolar the other phase is operated with 90 degree separation). Left Column: BPP with 8 ferrites, Right Column: DDP

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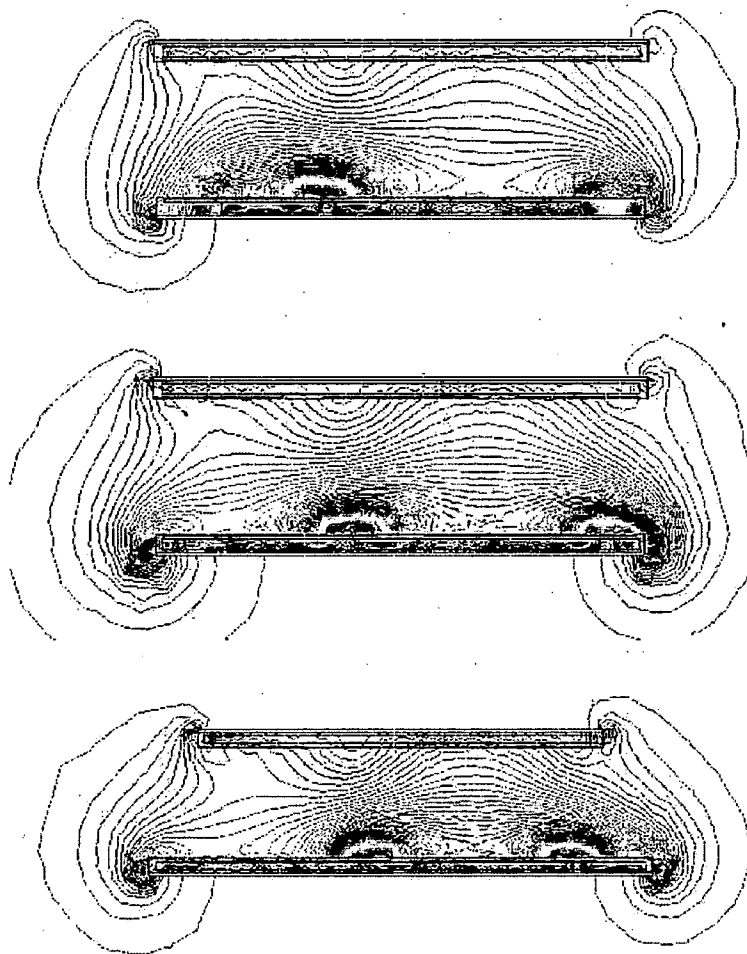


Figure 8: BPP with six (top), eight (middle) and ten (bottom) slabs making up each ferrite strip in the base, in the presence of a vertical offset DDQP pick-up at 0 degrees

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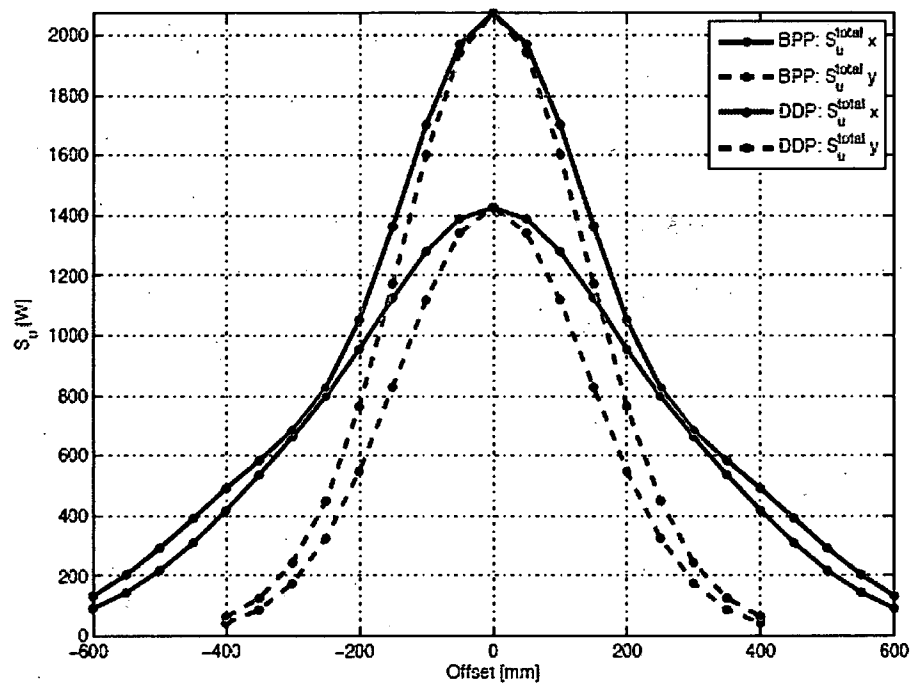


Figure 9: An example power transfer profile of a BPP(8) with a DDQP receiver

INTERNATIONAL SEARCH REPORT

International application No.

PCT/NZ2010/000160

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

H02J 7/00 (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)

WPI & EPODOC: magnetic, pad, permeable, core, induction, flux and similar terms

GOOGLE: : ratio overlap magnetic coils mutual inductance zero

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2007/090168 A2 (PARTOVI) 9 August 2007 Figs 4,5; paragraph[0054]	1-7, 18-19
Y	KWIAT, D et al, 'Calculation of the mutual induction between coplanar circular surface coils in magnetic resonance imaging' IEEE Transactions on Biomedical Engineering, Volume: 39 Issue: 5 Publication Date: May 1992 Page(s): 433 - 436	1-7, 18-19



Further documents are listed in the continuation of Box C



See patent family annex

* "A"	Special categories of cited documents: 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
"E"	earlier application or patent but published on or after the international filing date	"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
"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)	"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
"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"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
11 November 2010

Date of mailing of the international search report

01 DEC 2010

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/NZ2010/000160

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.: 20-22
because they relate to subject matter not required to be searched by this Authority, namely:
Claims 20-22 do not comply with Rule 6.2(a) because they rely on references to the description and/or drawings.
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:

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

Remark on Protest

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

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/NZ2010/000160

This Annex lists the known "A" publication level 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 Cited in Search Report				Patent Family Member			
WO	2007/090168	EP	2151037	US	2007182367	US	2007279002
		US	2009096413	WO	2008137996		
Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.							
END OF ANNEX							