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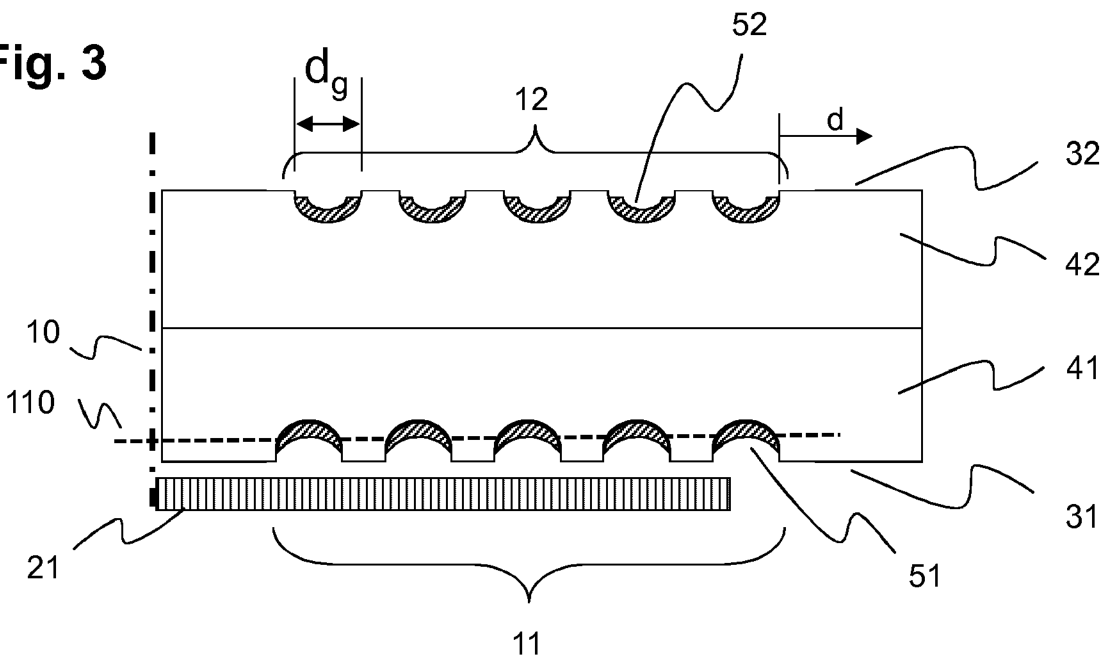
(54) **INDUCTIVE POWER TRANSFER SYSTEM**

(57) The present invention is concerned with an improved electrical insulation of an Inductive Power Transfer (IPT) system. According to the invention, a flat, two-dimensional conductor trace of a first coil of the IPT system is bent or shaped in a third dimension perpendicular to a coil plane encompassing the turns of the first coil, such that the edges of the conductor point away from a second, opposite coil of the IPT system. A geometric field grading achieved by such a conductor shape moves a direction and location of the electric field peaks occurring at the conductor edges away from the opposite coil of the IPT, and thus simplifies inter-coil insulation tasks.

Fig. 3



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Description

FIELD OF THE INVENTION

[0001] The invention relates to the field of power electronic applications such as power or frequency conversion based on power semiconductor switches operated via a gate drive. Specifically, it departs from an inductive power transfer system for providing power to a gate drive on elevated electrical potential.

BACKGROUND OF THE INVENTION

[0002] Medium-voltage and high-voltage power-electronic applications operate at system voltages of tens to hundreds of kilovolts. To reach these voltages with power semiconductors that have a blocking voltage on the order of a few kilovolts only, semiconductors are frequently connected in series. Most of the semiconductor packages in such a configuration are on an elevated voltage level and cannot be mounted directly on grounded components. Accordingly the auxiliary power that is needed to switch the semiconductors via a gate drive has to be supplied on potential. To this end galvanically insulated power supplies are used. Such power supplies transfer relatively low powers of the order of ten to a few hundred Watts to high voltages in the range of tens to hundreds of kilovolts. The functional voltage supplied at the output of the power supply is typically only 30-40 V and contrasts with the large operational voltage and corresponding insulation challenges.

[0003] Conventional galvanically insulated power supply systems include transformers with at least two windings that are inductively coupled. A coupling coefficient close to one is indicative of strong or efficient coupling, with the magnetic flux being guided in an essentially closed core around which the windings are wrapped. In such transformer designs, the electric insulation required between high-voltage winding and core is relatively complex and expensive, often results in a bulky design and even might cause reliability issues.

[0004] The insulation task is simplified by introducing a plane that separates high- and low-voltage parts of the power supply in so-called Inductive Power Transfer (IPT) systems. IPT designates inductive power transfer with a coupling coefficient clearly below 1, such as 0.3 or even lower. In an IPT system the magnetic flux between the windings is not guided by a core, but passes through an insulating material. The absence of a closed core offers the possibility of introducing an essentially planar electric insulation.

[0005] Fig. 1 depicts a cross section along a vertical system or rotational axis 10 of a conventional Inductive Power Transfer (IPT) system. The IPT System has a first spiral coil 11 with a front side facing a second spiral coil 12 that is displaced along the axis from the first coil by a distance g. In operation, the two coils are at different voltage levels and inductively coupled. Instead of a closed core, two plate-shape magnetic core elements 21, 22 may be used as "magnetic shields" to partially guide the magnetic flux. The coils are made of wire material with a circular cross section. The electric insulation between the coils may include a solid dielectric material, or a gas such as air separating the windings. Electric field peaks occur at edges or comers of either the coil or the magnetic core, as exemplarily indicated by the two arrows. Specifically, the edges are the outermost turns and the magnetic core may provoke field peaks that lead to corona discharge, internal partial discharge, and dielectric breakdown.

[0006] While it is possible to reduce the electric field enhancement on the conductors by increasing the diameter d_c of the circular conductor cross-section, this complicates manufacturing and unduly increases a system size. In particular, for an efficient energy transfer rather high frequencies and small currents are used, which favors the use of small conductors.

[0007] Fig.2 depicts a cross section along a vertical system axis of an IPT system with flat or planar coil conductor traces. The IPT system has a first spiral coil 11 with seven turns and with a front side facing a second spiral coil 12 that is arranged co-axially with and displaced along the system axis from the first coil. The coil conductors are printed traces on planar coil substrates 31, 32 as obtained for instance by conventional Printed Circuit Board (PCB) technology. PCB technology is fully automated and therefore cost efficient and highly reproducible. Optional disc- or plate-shaped magnetic core elements 21, 22 preferably made of ferrite improve the inductive coupling of the two coils. Again, electric field peaks occur at edges or corners of either the coil or the magnetic core, as exemplarily indicated by the two thick arrows.

DESCRIPTION OF THE INVENTION

[0008] It is an objective of the invention to improve the electrical insulation of an Inductive Power Transfer (IPT) system, and to reduce the distance between the coils and/or increase the insulation voltage. This objective is achieved by systems according to the independent claims. Preferred embodiments are evident from the dependent patent claims.

[0009] According to the invention, a flat, two-dimensional conductor trace of a first coil of the IPT system is bent or shaped in a third dimension perpendicular to a coil plane encompassing, or defined by, the turns of the first coil, such that the edges of the conductor point away from a second, opposite coil of the IPT system. A geometric field grading achieved by such a conductor shape moves direction and location of the electric field peaks occurring at the conductor edges away from the opposite coil of the IPT, and thus simplifies the inter-coil insulation tasks.

[0010] In particular, in an Inductive Power Transfer (IPT) System with a first coil facing a second coil, the first coil includes a conductor trace of essentially homogeneous thickness on, or applied to, a support surface. The conductor trace is delimited by a first and a second, specifically a radially inner and a radially outer, conductor edge wherein adjacent edge sections define a radial extension or width of the conductor trace. A, or even any, non-peripheral centre point of the conductor trace in-between the conductor edges is closer to the second coil than a nearest edge point of the conductor trace, in other words closer to the second coil than the one conductor edge point nearest to the centre point.

[0011] In case the conductor trace does not have a homogeneous thickness, for instance as a result of the manufacturing process chosen, the above closeness-condition holds at least for any point on the conductor surface facing the second coil.

[0012] In an advantageous embodiment of the invention the support surface includes a back surface of an insulating plate or board not facing the second coil. The plate comprises a groove trace of which the inner surface is at least partly coated with a conductive layer to form the conductor trace. Preferably, the grooves have a rounded cross-section with no corners and continuously narrowing down with increasing groove depth, more preferably the cross-section of the groove is approximately semi-circular with a groove diameter dg. In this embodiment, the electric field peak values in a direction of the second coil are further mitigated by the solid dielectric material of the insulating plate. Alternatively, the support surface may be a front surface of the plate facing the second coil and having bumps or embossments coated with a conductive layer.

[0013] In a preferred embodiment both the first and the second coil of the IPT system include conductor traces made from coated grooves in corresponding first and second insulating plates. The two insulating plates are not separated by an air gap of a specific width to achieve a specific electric insulation strength. Rather, the first and second insulating plates may be joined together or may even be one and the same plate, in which case the conductor trace support surfaces are opposing surfaces of a same dielectric support. Alternatively, an intermediate layer of an intermediate dielectric material having a dielectric constant that is lower than a dielectric constant of the insulating plates may be provided in between the first and the second insulating plates. Such intermediate layer provides for refractive, non-geometrical field grading, and particularly results in lower electric fields in the first and second insulating plates. Furthermore, the IPT system of the preferred embodiment has no additional conductive layer or guard ring for electric field grading between the first and the second insulating plates, excluding specifically the presence of a printed conductive surface or sprayed conductive varnish, and thus simplifying a manufacturing process of the IPT system.

[0014] In a preferred embodiment a conductor width, or a groove diameter, increases towards the inner and/or outer edges of the first coil, in order to further reduce the highest electric field values expected to occur, in case of uniform conductor width within the coil, at the innermost and/or outermost coil turns.

[0015] In a preferred embodiment the system includes a first core element in the form of a disc of magnetic material facing a rear side of the first coil to improve the magnetic coupling of the two coils. The first core element has a first planar surface area parallel to the first coil plane and delimited by a first circumference. The outermost turn of the first coil extends beyond the first circumference such as to partially screen the first core element.

[0016] In preferred variants of the invention outer turns of the first coil extend axially out of the first coil plane and are bent away from the second coil. The geometric field grading achieved by this arrangement decreases a maximum electric field strength at the surface of the coil conductors, and thus further simplifies the insulation tasks. An average, axial distance of the outermost turn from the first coil plane may even exceed a distance of the first planar surface area of the core element from the first coil plane. Hence, the coil is shaped towards and partly enclosing and electrically screening the first core element in order to decrease a maximum electric field strength occurring at the core element.

[0017] The IPT system is most beneficially employed in a power electronic system for power or frequency conversion, static VAr compensation (Statcom applications), or motor drives. The power electronic system has power semiconductors switches controlled, driven or operated via controllers or gate drives on medium or high potential that in turn are supplied with power via IPT systems from a power source on ground potential.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] The subject matter of the invention will be explained in more detail in the following text with reference to preferred exemplary embodiments which are illustrated in the attached drawings, in which:

Fig.1 is a cross section of a conventional Inductive Power Transfer (IPT) system;

Fig.2 is a cross section of an IPT system with planar conductor traces;

Fig.3 is a cross section of an exemplary IPT system according to the invention; and

Fig.4 depicts an electric field strength for the IPT systems of Fig.2 and Fig.3.

[0019] In principle, identical parts are provided with the same reference symbols in the figures.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0020] Fig.3 depicts a cross section along a vertical system axis 10 of an exemplary IPT system according to the invention. The IPT system has a first spiral coil 11 with five turns that faces a second spiral coil 12 arranged co-axially with and displaced along the system axis from the first coil. A first electrically insulating plate or board 41 has a rear or back surface 31 facing away from the second coil. The back surface comprises semi-circular grooves, or channels, formed in the insulating plate. A conductor trace 51 of the first coil 11 is formed by coating the inner surfaces of the grooves. The turns of the first coil define a first coil plane 110 for reference purposes. An optional disc- or plate-shaped magnetic core element 21 made of ferrite may be used as "magnetic shield" to partially guide the magnetic flux and improve the inductive coupling of the two coils.

[0021] Likewise, a second electrically insulating plate 42 has a rear surface 32 facing away from the first coil. The back surface comprises semi-circular grooves with a diameter dg of a few millimetres formed in the insulating plate. A conductor trace 52 of the second coil 12 is formed by coating the inner surfaces of the grooves. While the conductor traces 52 of the second coil have an almost uniform thickness, the conductor traces 51 of the first coil are shown to be thicker in the middle, however, both traces 51, 52 are shown with an exaggerated thickness for illustrative purposes.

[0022] Fig.4 depicts a comparison of the simulated maximum electric field strengths on the support surface adjacent to the outer edge of the outermost turn as a function of the distance d in the two configurations of Fig.2 (broken line) and Fig.3 (solid line). Field enhancements at the edge of the conductor trace of the outermost turn are much stronger for flat traces than for conductor traces with edges bent away from the opposite coil.

[0023] The two insulating support plates 41, 42 may be separated by an air gap as shown in Fig.2, or may be combined in one plate without air gap in-between as shown in Fig.3.

[0024] The diameter or width dg of the grooves can be chosen rather large to obtain a more homogeneous electric field and reduced field peaks. For a given cross section of the grooves the coating height can then be adapted to the operation frequency and current level. Much less conducting material will be used resulting in lighter, smaller design that is more adapted to the high frequency low power operation.

[0025] The plates including grooves can be manufactured in various ways, in particular using technologies known for MID (molded interconnect devices), including "laser direct structuring" (LDS), "two-shot molding", and "hot pressing" where the grooves are formed in a flat plate of thermoplastic material at elevated temperature. The mentioned technologies are suitable for mass production and can be cost efficient.

[0026] Applying conductor traces on non-planar support surfaces may be accomplished by various manufacturing technologies including 3D MID (3 Dimensional Molded Interconnect Device) technology. A molded interconnect device (MID) is an injection-molded thermoplastic part with integrated electronic circuit traces. 3D MID technology combines high temperature thermoplastics substrate/housing with structured metallization circuitry into a single part through selective metallization.

[0027] If the conductive layer is applied to the groove by coating, there is no air gap between conductive layer and solid material leading to partial discharge. The conductor traces may be inner layer traces completely surrounded by solid dielectric material, similar to multilayer printed circuit boards that have trace layers inside the board obtained by laminating a stack of materials in a press by applying pressure and heat. Remaining field peaks near the conductor are then located fully within the solid material, which has a higher dielectric strength than air.

[0028] While the invention has been described in detail in the drawings and foregoing description, such description is to be considered illustrative or exemplary and not restrictive. Variations to the disclosed embodiments can be understood and effected by those skilled in the art and practising the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain elements or steps are recited in distinct claims does not indicate that a combination of these elements or steps cannot be used to advantage, specifically, in addition to the actual claim dependency, any further meaningful claim combination shall be considered disclosed.

Claims

1. Inductive Power Transfer System with a first coil (11) facing a second coil (12), wherein the first coil (11) includes a conductor trace on a support surface (31) having two conductor edges, **characterized in that** a centre point of the conductor trace is closer to the second coil (12) than a nearest edge point on one of the conductor edges.

2. The system of claim 1, wherein the support surface (31) is facing away from the second coil (12) and is part of an insulating plate (41) comprising a groove coated with a conductive layer to form the conductor trace.

3. The system of claim 2, wherein the second coil (12) includes a second conductor trace on a second support surface (32) having two second conductor edges, and wherein a centre point of the second conductor trace is closer to the first coil (11) than a nearest edge point on one of the second conductor edges, and wherein the second support surface includes a coated groove surface facing away from the first coil, **characterized by** the absence of an air gap in between the first and second coil.

4. The system of claim 1, **characterized in that** a conductor width of the conductor trace increases towards an inner and/or an outer edge of the first coil.

5. The system of claim 1, including a first core element (21) facing a rear side of the first coil and having a first planar surface area delimited by a first circumference, **characterized in that** the outermost turn of the first coil extends beyond the first circumference.

6. The system of any of claims 1 to 4, wherein inner turns of the first coil are arranged in a first coil plane (110), **characterized in that** an outer turn of the first coil extends out of the first coil plane away from the second coil.

7. The system of claim 5, wherein inner turns of the first coil are arranged in a first coil plane (110) and wherein the first planar surface area of the first core element is parallel to the first coil plane, **characterized in that** a distance of the outermost turn of the first coil from the first coil plane exceeds a distance of the first planar surface area of the core element from the first coil plane.

8. A power electronic system with a power semiconductor switch controlled by a controller supplied with power via an IPT system as claimed in any of the preceding claims.

Fig. 1

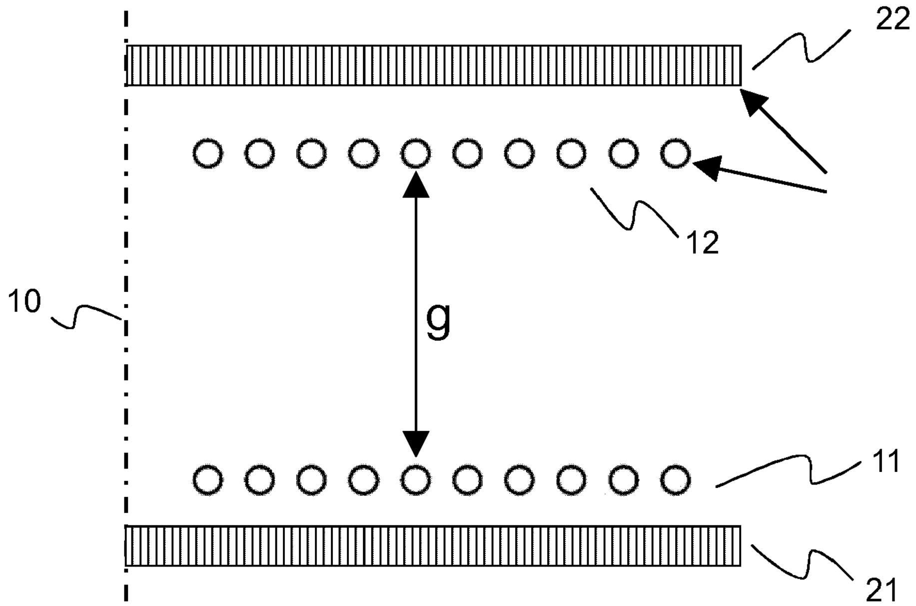


Fig. 2

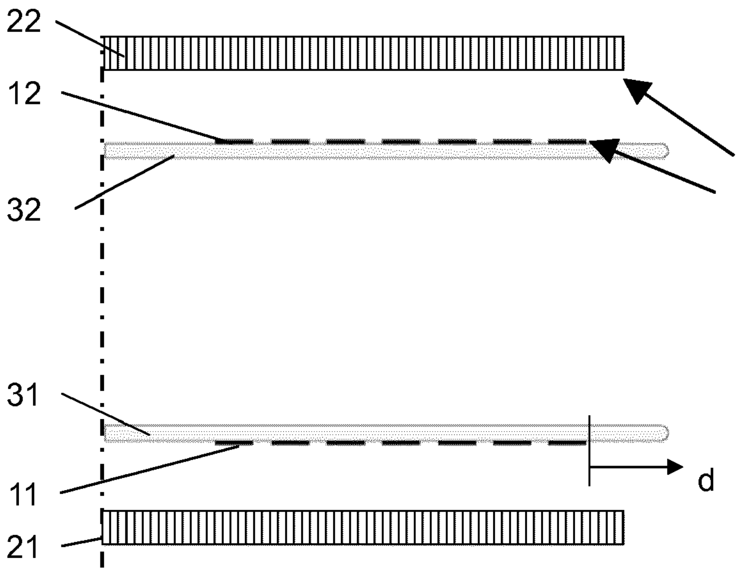


Fig. 3

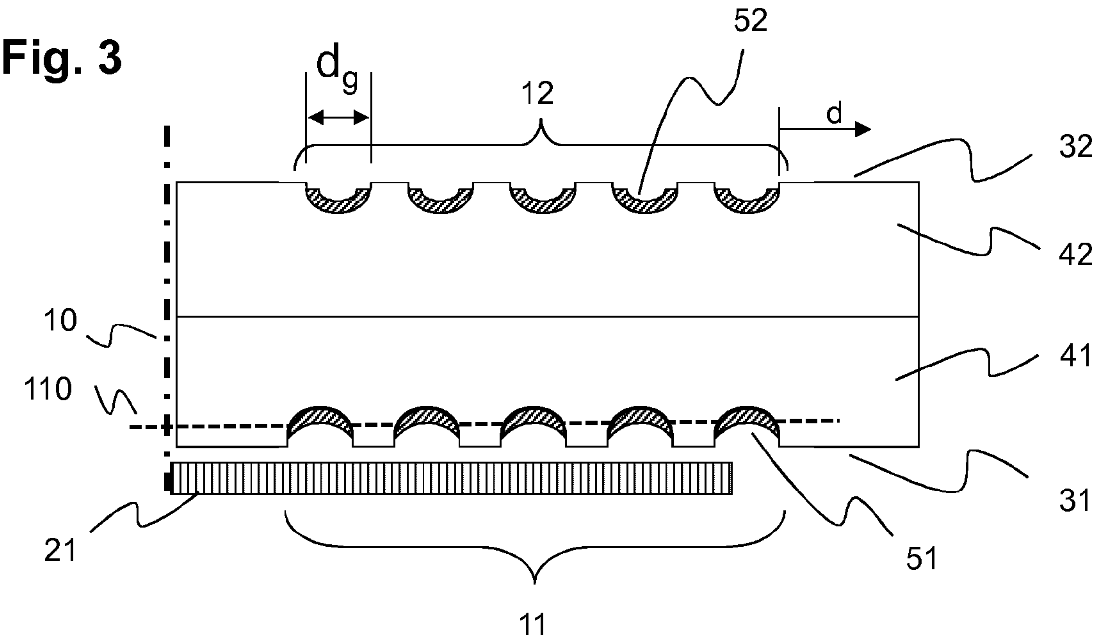
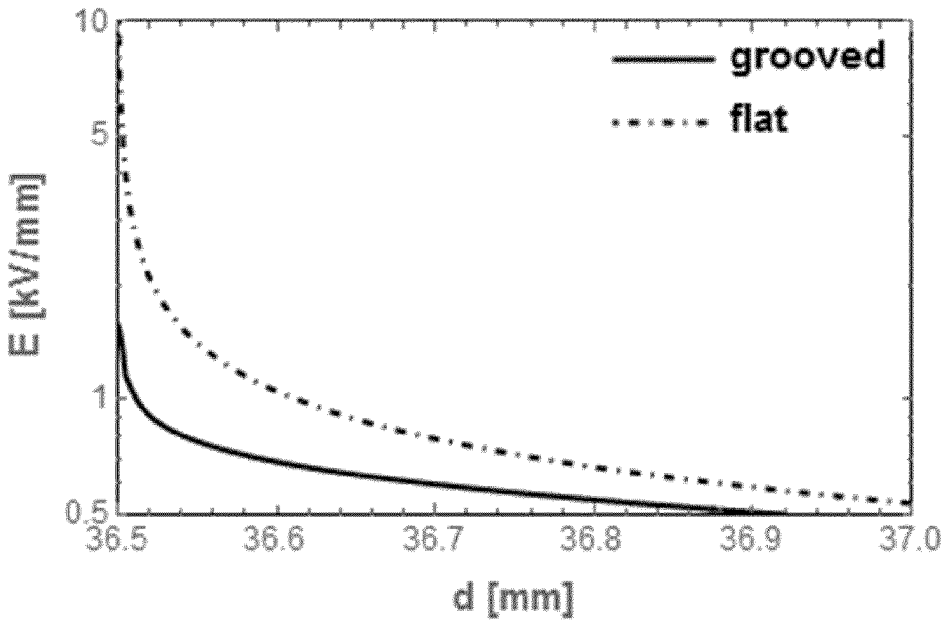

52
d
g
12
d
32
42
10
41
110
31
21
51
11

Fig. 4


10
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1
0.5
E [kV/mm]
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flat
36.5
36.6
36.7
36.8
36.9
37.0
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EUROPEAN SEARCH REPORT

Application Number
EP 15 18 1981

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	24 February 2016	Kardinal, Ingrid

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X : particularly relevant if taken alone
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EUROPEAN SEARCH REPORT

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Place of search	Date of completion of the search	Examiner
Munich	24 February 2016	Kardinal, Ingrid

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