



- (51) International Patent Classification:
G01R 33/38 (2006.01) *G01R 33/3875* (2006.01)
- (21) International Application Number:
PCT/IB2012/051557
- (22) International Filing Date:
30 March 2012 (30.03.2012)
- (25) Filing Language: Italian
- (26) Publication Language: English
- (30) Priority Data:
TO2011A000290 31 March 2011 (31.03.2011) IT
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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, QA, RO, RS, RU, RW, 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, RW, 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, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- of inventorship (Rule 4.17(iv))

Published:

- with international search report (Art. 21(3))

(54) Title: OPEN MAGNETIC ASSEMBLY WITH THREE ACTIVE SIDES, IN PARTICULAR FOR MAGNETIC RESONANCE IMAGING

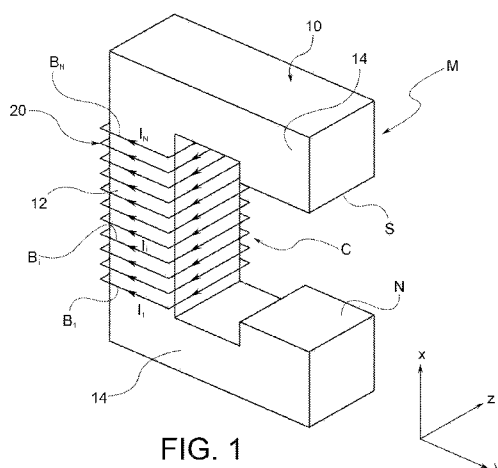


FIG. 1

(57) Abstract: What is described is an open - structure magnetic assembly comprising a first and a second source of magnetic field (10, 20), which define a magnet cavity (C) open at least at a side. The first source of magnetic field (10) comprises a magnetic structure having a C- shaped volume, including a middle portion (12) defining a back wall of the cavity (C) and a pair of lateral portions (14) forming at the ends respective facing poles (N, S), which is arranged for generating in a gap region a substantially uniform magnetic field component oriented along the direction connecting the poles. The second source of magnetic field (20) comprises at least one winding extended around a portion (12; 14) of the magnetic structure so as to have a plurality of conducting sections lying on a surface within the cavity, adapted to be passed through by a unidirectional current flow whereby they generate in the space volume facing them a second substantially unidirectional magnetic field having an orientation congruent with that of the first magnetic field generated by the first source (10).



Open magnetic assembly with three active sides, in particular for magnetic resonance imaging

The present invention relates to the generation of magnetic fields, in particular for magnetic resonance imaging.

More specifically, the invention relates to a magnetic assembly according to the preamble of Claim 1.

Magnetic resonance imaging (MRI) requires a high-intensity magnetic field with a high degree of uniformity in a region of interest. When imaging human subjects, it is also necessary for the structure of the magnet to be such as to make it possible to easily position the subject to be examined, such that the volume to be examined is located at the region of homogeneity of the field, that is at the region in which the magnetic field has a constant intensity and is unidirectional.

Electromagnetic fields are governed by Maxwell's equations, which do not acknowledge the existence of uniform fields in air, if not in volumes completely contained within elements generating the fields themselves. Generally, however, the cavity of the magnet is provided for positioning the subject to be examined. It is therefore not possible a priori to realize a magnet which provides a perfectly homogeneous field and at the same time has openings adapted for the introduction of the patient.

According to the theory of magnetic fields, a region of uniformity of the magnetic field in a volume which is not passed through by electric currents, which is precisely the region of interest for the applications involved here, can exist exclusively in the area around a saddle point. This is a result of the fact that maxima or minima of the field cannot exist in a volume which is not passed through by currents. In addition, the intensity of the field decreases as the distance from the generating current increases.

The art of realizing magnets adapted for magnetic resonance imaging has therefore been targeted at the specification of techniques which would make it possible to best

approximate the desired conditions using magnetic field generators which are constituted by conducting windings, within which a continuous electric current flows, or by blocks of magnetized material. The techniques used in this respect are manifold and differ substantially depending on whether the field is generated by windings or by blocks of magnetized material. Fundamentally, however, the physical principles are the same.

The current state of the art in the field of magnetic resonance imaging (MRI) requires field intensities which range from at least 1 Tesla to values of 8 or 9 Tesla. The most common design for a magnetic field generator intended for MRI applications is that of a series of circular coils which are wound with different axial diameters and spacings on a single cylindrical axis of symmetry. An appropriate selection of the dimensions of the coils and of the position thereof makes it possible to obtain fields which have the required intensity and homogeneity characteristics in the volume of interest, which is situated close to the middle of the structure. The use of external coils in which the current flows in a direction opposite to that in internal coils additionally makes "shielding" possible, that is the reduction of the field in the regions in which it is not required (or even harmful).

As a result of this structural selection, the magnet assumes the form of a cylinder, within which the patient is positioned. The imaging region is close to the centre of the cylinder and is therefore difficult to access from the outside. Since it is often the case that the head (encephalon examinations) or the thorax or the waist of the patient (cardiac or abdominal examinations) is positioned in the imaging region, said patient is enclosed in the cylindrical volume of the magnet, which often creates instances of anxiety, discomfort or open claustrophobia, which make examination impossible in a considerable number of cases.

Another structure which is used is the "open" configuration, in which a ferrous core comprising two circular poles or poles of another shape is excited by means of windings or permanently magnetized material. This type of magnets is limited in terms of the maximum field intensity which can be achieved by the maximum residual magnetization of the available permanent magnets or by the saturation characteristics of the iron, which forms the core.

The use of permanent magnetic materials limits the maximum achievable field intensity, which is of the order of 0.5-0.8 Tesla, a value lower than the levels commonly offered by superconducting magnets.

In fact, the structures which have been used to date in practice in magnetic resonance imaging are configurations with windings with separate coils, or magnets with a C-shaped or H-shaped volume.

US 5,592,090, US 5,305,749 and US 5,347,252 describe an open-structure magnetic assembly having a single source of magnetic field in the form of a winding, and a structure made of a material having a high magnetic permeability for propagation of the field excited by the source and for establishing a uniform field in a region of a cavity intended to receive a patient.

These configurations are commonly referred to as configurations with two active sides, since only two surfaces actively generate the magnetic field in the region of interest.

In general, a uniform magnetic field is generally generated in a region of interest within a cavity or a volume of open space, accessible to a patient, to the detriment of efficiency, this being defined as the relationship between the energy of the magnetic field present in the region of space of interest and the total energy used to generate said field, that is as the relationship between the intensity of the magnetic field in the region of space of interest and the peak current density which flows in the windings which excite said field.

It is immediately evident to an expert in the field that the efficiency of a magnetic assembly is lower the greater the number of open sides of the structure. By way of example, a solenoid magnet or a "tunnel" magnet is open at the extreme opposite sides, perpendicular to the direction of the magnetic field vector, whereas a C-shaped magnet is open at four sides parallel to the field (envelope of the gap), so the latter configuration, which is more comfortable for the patient, suffers from a limited efficiency with respect to the solenoid configuration.

The quality of the images which can be obtained, up to a resolution in the sub-millimetre range, is determined essentially by the signal-to-noise ratio of the assembly. The noise, which is typically due to contributions of thermal origin, cannot be reduced beyond the limits fixed by the body temperature of the patient. On the contrary, the useful signal is proportional to the intensity of the magnetic field which is established in the region of interest, as a result of which it is necessary to generate high field intensities in this region in order to obtain a better quality of the images and reduced examination times and therefore reduced times for which the patient is exposed to the magnetic radiation.

The theoretical and practical problem of designing an open magnet is thus reduced to the problem of determining a configuration which is adapted to generate a magnetic field having the required intensity and homogeneity characteristics in a region of interest which is where possible far from the magnetic structure, and is therefore accessible, so as to guarantee functionality in particular magnetic resonance imaging applications, for example for studying the human motor cortex, where it is necessary for the patient to be kept in a natural upright or seated position, with freedom to move.

It is an object of the present invention to realize an open-structure magnetic assembly adapted to produce a uniform magnetic field of increased intensity which is able to guarantee magnetic resonance imaging in a region of interest accessible to a patient, in which the magnetic field is generated with greater efficiency than in the case of the known configurations.

According to the present invention, this object is achieved by a magnetic assembly having the features indicated in Claim 1.

Particular embodiments form the subject of the dependent claims, the content of which should be regarded as an integral or integrating part of the present description.

The invention also relates to an apparatus for magnetic resonance imaging, as claimed.

Briefly, the present invention is based on the principle of obtaining a homogeneous

magnetic field in a region of interest by the addition of fields of similar intensities which are generated by two different main structures of an open-structure magnetic assembly, which form a magnetic assembly with three active sides.

The invention descends from the consideration that, in the case of an open magnetic structure, the key to increasing the intensity of the magnetic field is to limit the "degree of opening", that is the opening of the solid angle subtended by the total opening as seen from the centre of the region of interest, by attributing an active role in the generation of the magnetic field to the back wall of the cavity, which merely has a structural function in a conventional C-shaped structure.

The active role of the back wall of the cavity is obtained by imposing a uniform linear current density on the wall or in the proximity thereof, closing the current on return paths which are arranged so as neither to obstruct the opening, nor increase the dimensions of the structure as a whole.

More specifically, the magnetic assembly according to the invention includes a first source of magnetic field in the form of a prismatic C-shaped magnetic structure, which defines an open magnet cavity within which a subject to be examined can be positioned. The C-shaped magnetic structure is, for example, a C-shaped body formed by a volume of permanently magnetized material which is characterized by a relative magnetic permeability close to 1, and/or by a hollow volume with an associated arrangement of excitation windings, or a corresponding structure of windings, the poles of which define between them a region of a uniform magnetic field.

A second source of magnetic field is joined to the main C-shaped magnetic structure and is formed by windings which encompass at least one branch of the C-shaped structure and define at least a unidirectional current distribution on an internal surface of the cavity, adapted to generate, in the gap region of space present between the poles of the C-shaped magnetic structure, a magnetic field of an intensity which is comparable to that of the field produced by the first source, and having the same direction as the latter.

The magnetic assembly according to the invention makes it possible to obtain a magnetic field having the required intensity and homogeneity characteristics in a region of interest situated in the internal volume of the cavity, between the back wall of the latter and the poles of the C-shaped structure, and the structure of the assembly is such as to make it possible to easily position the subject to be examined so that the volume to be examined is located at the region of homogeneity of the field.

Further features and advantages of the invention will be explained in more detail in the following detailed description of an embodiment thereof, provided by way of non-limiting example and referring to the appended drawings, in which:

Figure 1 is a schematic illustration of a first embodiment of the magnetic assembly according to the invention;

Figures 2a and 2b are corresponding schematic illustrations of the embodiment shown in Figure 1;

Figure 3 is a schematic illustration of a second embodiment of the magnetic assembly according to the invention;

Figure 4 is a schematic illustration of a variant of the magnetic assembly shown in Figure 3;

Figure 5 is a schematic illustration of a third embodiment of the magnetic assembly according to the invention;

Figure 6 is an exemplary illustration of an apparatus for magnetic resonance imaging which utilizes a magnetic assembly of the type shown in Figure 1; and

Figure 7 is a schematic illustration of the first embodiment of the magnetic assembly according to the invention, provided with correcting lateral windings for correction of the overall magnetic field.

A magnetic assembly according to the invention, denoted by M, is illustrated in the currently preferred embodiments and variants with reference to Figures 1-5, and comprises a first source of magnetic field 10 and a second source of magnetic field 20, which are coupled, are electrically independent and define a magnet cavity C open at least at a side, each of which generating an additive contribution to the magnetic field resulting in a region of interest within said cavity.

The first source of magnetic field 10 is formed by a prismatic C-shaped magnetic body which is symmetrical with respect to the common plane of symmetry yz of the source. The C-shaped magnetic body is formed by a volume of magnetized material, or else in magnetically corresponding terms an arrangement of air core windings in accordance with a C-shaped prismatic envelope.

The C-shaped magnetic structure of the first source of field 10 includes a middle section 12 defining a back wall of the cavity C, from the ends of which two parallel lateral sections 14 branch off, these being substantially orthogonal to the middle section and defining at the free ends respective facing poles N, S.

This source is arranged for generating a main magnetic field component which is oriented and has a substantially uniform intensity in a region of space present between the poles, the intensity of which decreases as the distance from the middle gap region increases and towards the interior of the cavity.

The second source of field 20 comprises a current conducting structure, preferably a current superconducting structure, which includes at least one continuous winding, or an arrangement of coaxial continuous windings, or more preferably a plurality of separate, electrically independent, coils (for example planar coils), of wires or conducting bands wound around at least one section of the magnetic structure of the first source of field 10.

In other words, the second source of field 20 defines at least one substantially two-dimensional composite structure within the magnet cavity C which is adapted to sustain a broad two-dimensional distribution of current, which contributes to generating a useful magnetic field, the flux lines of which are superposed in direction and sense with the flux lines of the magnetic field generated between the poles of the first source of field, thus increasing the intensity of the homogeneous field in the region of interest present within the cavity.

In an electric model, the second source of magnetic field can be represented in theory by a

current sheet adjacent to the back wall of the assembly, adapted to be passed through by a unidirectional current flow distributed on a planar or curved surface, determined by the side-by-side arrangement of a plurality of substantially parallel and aligned current paths belonging to a plurality of different windings, and indicated schematically in the figure by the parallel arrows of circulation of the current within the turns.

In the space volume facing the back wall and present between the latter and the poles N, S, on the outside of the coils, the overall current generates a substantially unidirectional additional magnetic field having an orientation perpendicular to the direction of the flow of current generated within the cavity, which decreases as the distance from the back wall increases.

The magnetic assembly M defines a magnet cavity C open on three sides, within which there is located an accessible region of space of interest, and has an overall structure which is symmetrical with respect to a longitudinal mid-plane of symmetry yz. Both the sources generate a contribution to the resulting magnetic field, identified hereinbelow respectively as main magnetic field (generated by the first source 10) and additional magnetic field (generated by the second source 20).

In a first embodiment shown schematically in Figure 1, the second source of field 20 includes a solenoid winding or, more preferably, a plurality of parallel planar coils $B_1, \dots, B_i, \dots, B_N$ wound around the middle section 12 of the C-shaped magnetic structure of the assembly, each being passed through by a respective current $I_1, \dots, I_i, \dots, I_N$. The configuration with parallel planar coils is preferable since it allows for better local control of the density of current which forms the second source of field, making it possible to modulate the intensity of current circulating in each coil independently of the others, and thereby to actively control the curvature of the field lines in the region of interest.

The conducting segments of the coils which are closest to the region of interest within the cavity contribute to the generation of a magnetic field, the flux lines of which are superposed in direction and sense with the flux lines of the magnetic field generated between the poles of the first source of field, ultimately contributing to an increase in the

intensity of the homogeneous field in the region of interest.

The high-efficiency magnetic structure shown in Figure 1, in which the middle section of the portion of return of the magnetic flux of the C-shaped magnetic structure is surrounded by coils having a rectangular cross section, is schematized further in Figure 2a, together with the corresponding magnetic configuration of Figure 2b.

Indeed, if the coils are transformed into corresponding magnetized blocks, the resulting magnetic charges assume the configuration shown in Figure 2b. The resulting field shows a saddle point in a position within the cavity, which is a required condition for realizing a uniform field region. The optimization of this configuration keeps to the attainment of the maximum extension of the uniform region and of the maximum field intensity within the latter.

In this respect, the following considerations are presented:

- both the poles of the C-shaped magnetic structure and the back wall of the cavity contribute to the overall field intensity, or rather the two contributions do not cancel one another out;
- the contribution of the coil is at a maximum the closer the region of uniformity of the field is thereto and the further away the opposite wall, in the proximity of which is located the return path of the conductors of the same coil;
- the region of uniformity cannot be too close to the coil, as it is necessary to take into account the dimensions of a cryostat for controlling the temperature if the coil is made of superconducting material;
- the extension of the region of uniformity depends on the result of superposition of the opposite gradients of the fields generated by the coil and by the C-shaped magnetic structure;
- the extension of the region of uniformity in the direction x of depth of the cavity of the magnetic assembly depends essentially on the position, along the axis x , of the poles N, S and on the relationship between the currents in the C-shaped magnetic structure and in the coils;
- the extension of the region of uniformity in the direction y (width of the cavity) can

be controlled by way of spatial modulation of the current in the coils, with the modulation not having a notable effect on the extension of the region of uniformity in the direction x , setting aside variations in the overall current;

- the extension of the region of uniformity in the direction z (height of the cavity) depends essentially on the extension of the magnet in the same direction z .

A magnetic assembly of the type shown in Figure 1 can be described by way of a limited number of parameters, respectively:

- W_{xC} : width on the axis x of the poles;
- W_{xS} : width on the axis x of the coils;
- Δx : distance between the poles and the active back wall of the cavity;
- W_y : magnetic gap;
- W_z : length of the magnet;
- R : relationship between the mean current density in the coils and that in the C-shaped volume structure;
- N_c : number of planar coils which constitute the second source of field;
- W_{yp} : height of each planar coil (which has to be less than $W_y \times N_c$ to also take into account the space which the mechanical structure needs for supporting and housing the coils).

Given the aforementioned geometrical parameters, it is possible to determine the value of R which maximizes the extension of the region of uniformity in x .

In consideration of the linearity of the equations which govern the system, the spatial modulation of the currents of the coils can be determined by calculating the pseudo inverse matrix of $M \times N_c$, which represents the contribution of N_c planar coils in M points distributed on a region of uniformity along y .

If current modulation is applied, it is necessary to control the mean current in the coils, since the homogeneity of the field is affected on the axis x . A satisfactory design result is obtained after few iterations.

The overall extension of the region of uniformity is a function of the original geometrical parameters, and the exact position of the middle of the region of uniformity along the axis x cannot be determined a priori. Following selection of various values for the initial parameters, the structure of the magnetic assembly can be optimized during the design stage by way of a combination of metaheuristic single-objective or multiobjective optimization algorithms (for example, GODLIKE, a free software procedure from MATLAB, The MathWorks, Natick, MA).

In a second embodiment, shown schematically in Figure 3, the second source of field 20 includes a pair of specular planar coils B'_1 , B'_2 arranged side by side, in which a symmetrical circulation of current is established, wound concentrically around a respective lateral section 14 of the C-shaped magnetic structure of the assembly and passed through by a respective current I'_1 , I'_2 .

The parallel conducting segments of the planar coils which are arranged within the cavity contribute to the generation of a magnetic field, the flux lines of which are superposed in direction and sense with the flux lines of the magnetic field generated between the poles of the first source of field, contributing to an increase in the intensity of the homogeneous field in the region of interest.

In a variant of the second embodiment, shown schematically in Figure 4, the second source of field 20 includes a pair of specular arrangements of planar coils, each arrangement comprising a plurality of planar coils B''_{1a} , ..., B''_{1n} and respectively B''_{2a} , ..., B''_{2n} of increasing perimeter, wound around a respective lateral section of the C-shaped structure of the assembly according to a radial or fan arrangement, and passed through by respective currents I''_{1a} , ..., I''_{1n} , I''_{2a} , ..., I''_{2n} . In particular, each coil comprises a side or a portion of the conductive path within the cavity, which lies on a surface adjacent to the back wall of the same cavity, for example on a plane parallel to the back wall, whereas the remaining conducting segments of each coil lie on planes substantially parallel to the surface (to the sides) of the lateral sections 14 of the C-shaped magnetic structure which they encompass.

The parallel conducting segments of the planar coils arranged within the cavity contribute

to the generation of a magnetic field, the flux lines of which are superposed in direction and sense with the flux lines of the magnetic field generated between the poles of the first source of field, contributing to an increase in the intensity of the homogeneous field in the region of interest.

This variant is distinguished by reduced external dimensions with respect to the embodiment shown in Figure 3.

In a third embodiment, shown schematically in Figure 5, the volume structure of the first source of field 10 includes a curved middle section 12, with the concavity facing towards the cavity C of the magnetic assembly.

The second source of field 20 includes a pair of specular arrangements of planar coils, each arrangement comprising a plurality of planar coils $B'''_{1a}, \dots, B'''_{1n}$ and respectively $B'''_{2a}, \dots, B'''_{2n}$ of increasing perimeter, wound around a respective lateral section of the C-shaped magnetic structure of the assembly according to a stacked arrangement on parallel planes, and passed through by respective currents $I'''_{1a}, \dots, I'''_{1n}, I'''_{2a}, \dots, I'''_{2n}$. In particular, each coil comprises a side or a portion of the conductive path within the cavity, which lies on a curved surface parallel to the back wall of the same cavity, whereas the remaining conducting segments of each coil lie on planes substantially parallel to the surface (to the sides) of the lateral sections 14 of the C-shaped volume structure which they encompass.

The parallel conducting segments of the planar coils arranged within the cavity contribute to the generation of a magnetic field, the flux lines of which are superposed in direction and sense with the flux lines of the magnetic field generated between the poles of the first source of field, contributing to an increase in the intensity of the homogeneous field in the region of interest.

For simplicity of illustration, in the appended figures the coils are depicted by a single continuous line with quadrangular development, on some segments of which an arrow indicates the direction in which the current circulates. An expert in the field will understand, however, that the coil is formed in any case by a set of turns, which can vary in

number typically from 1 to many thousands and the extension of which in space can consequently vary in diameter and thickness, as a function of the number of turns and of the winding structure adopted (for example "pancake" or "double pancake" planar coils). It is not mandatory for the coils to have the same geometrical shape, it being possible to realize windings of an approximately quadrangular (with rounded vertices) or circular or else elliptical form, for example as a function of the cross section of the C-shaped structure which the coils encompass.

The quadrangular section of the volume structure is also purely indicative, it being possible to envisage other polygonal shapes, a circular shape or other curved shapes or more complex shapes with a succession of straight sides and curved sides, such as overall structures with a modified C-shape, obtainable by bending one or more sections.

It is noted that, in all the exemplary embodiments described, the coils generate an additional magnetic field which is electrically and magnetically independent of the field generated by the permanent magnet or by the corresponding configuration of air core solenoid windings. In addition, the configurations shown do not require the use of windings extended around non-planar surfaces, which would be particularly expensive to realize.

An exemplary illustration of the use of a magnetic assembly of the type shown in Figure 1 for realizing an apparatus A for magnetic resonance imaging is shown schematically in Figure 6.

The structure of the first source of field 10 forms a back wall W of the apparatus at the middle section 12 and lateral walls L at the lateral sections 14. The structure of the second source of field 20 transversely surrounds the back wall W of the structure of the first source of field 10, leaving a volume of open space C, accessible from three sides.

In the embodiments and variants shown in Figures 3 to 5, the structure of the second source of field 20 transversely surrounds the lateral walls L of the structure of the first source of field 10, always leaving a volume of open space C, accessible from three sides.

As can be clearly understood, a patient H can be accommodated in the cavity C of the assembly, in an easily accessible manner, and positioned in the region of interest between the poles and the back wall, where he can be exposed to a homogeneous magnetic field over the entire volume which is to be examined. The patient can be housed in the cavity in a seated or standing position, and can enjoy the possibility, although limited, to move in the space.

Advantageously, it is easy to add a pair of correcting lateral windings B_C for correction of the overall magnetic field generated by the contributions of the first and of the second source, which are arranged on surfaces which are planar, coplanar or parallel to the poles N, S and extend over the entire depth of the structure of the magnetic assembly, as shown in Figure 7, and are able to disturb the field generated to recover possible dishomogeneities owing to residual errors and manufacturing tolerances.

It has been shown that a magnetic assembly according to the invention, which maximizes the efficiency and the homogeneity of an apparatus for magnetic resonance imaging, in particular for imaging the motor cortex of a patient who can retain freedom of movement, achieves a magnetic field of an intensity equal to 2T with current densities which are compatible with the use of superconducting coils of NbTi at the temperature of the liquid helium.

Clearly, without departing from the principle of the invention, the embodiments and the details of construction may differ considerably from those described and illustrated purely by way of non-limiting example, without thereby departing from the scope of protection of the invention defined by the appended claims.

CLAIMS

1. An open-structure magnetic assembly, adapted to generate a homogeneous magnetic field in an accessible region of space, comprising a first and a second source of magnetic field (10, 20), which define a magnet cavity (C) open at least at a side, each of which generating a contribution to the resulting magnetic field,

characterized in that the first source of magnetic field (10) comprises a magnetic structure having a relative magnetic permeability close to 1, including a middle portion (12) defining a back wall of the cavity (C) and a pair of lateral portions (14) forming at the ends respective facing poles (N, S), which is arranged for generating in a gap region a substantially uniform magnetic field component oriented along the direction connecting the poles, whose intensity has a gradient in a direction away from the gap region; and

in that the second source of magnetic field (20) comprises at least one conducting or superconducting winding ($B_1, \dots, B_N; B'_1, B'_2; B''_{1a}, \dots, B''_{1n}, B''_{2a}, \dots, B''_{2n}; B'''_{1a}, \dots, B'''_{1n}, B'''_{2a}, \dots, B'''_{2n}$) extended around a portion (12; 14) of the magnetic structure so as to have a plurality of conducting sections lying on a surface within the cavity, adapted to be passed through by a unidirectional current flow ($I_1, \dots, I_N; I'_1, I'_2; I''_{1a}, \dots, I''_{1n}, I''_{2a}, \dots, I''_{2n}; I'''_{1a}, \dots, I'''_{1n}, I'''_{2a}, \dots, I'''_{2n}$) whereby they generate in the space volume facing them a second substantially unidirectional additional magnetic field having an orientation congruent with that of the first magnetic field generated by said first source (10), whose intensity has a gradient adapted to compensate, in a region of interest, the gradient of the intensity of the field generated by the first source (10).

2. A magnetic assembly according to Claim 1, wherein the magnetic structure that is the first source of magnetic field comprises a C-shaped volume of magnetized material or an arrangement of air core windings having a C-shaped envelope.

3. A magnetic assembly according to Claim 1 or 2, wherein the second source of field (20) includes a solenoid winding extending around the middle portion (12) of the magnetic structure of the first source of magnetic field (10).

4. A magnetic assembly according to Claim 1 or 2, wherein the second source of field

(20) includes a plurality of parallel planar coils ($B_1, \dots, B_N$) wound around the middle portion (12) of the magnetic structure of the first source of magnetic field (10).

5. A magnetic assembly according to Claim 4, wherein the intensity of the current ($I_1, \dots, I_N$) flowing in each coil ($B_1, \dots, B_N$) is controlled in an independent way, so as to locally control the current density of said second source of magnetic field (20).

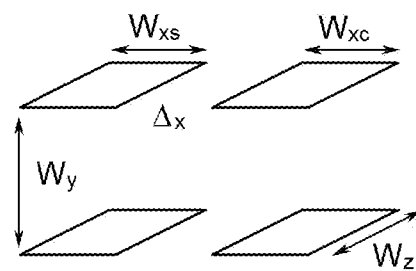
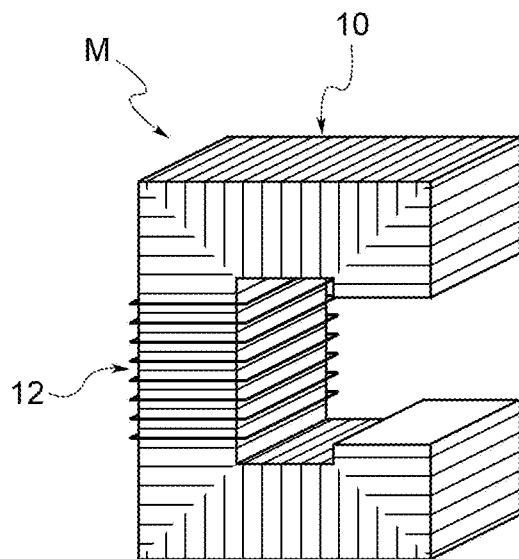
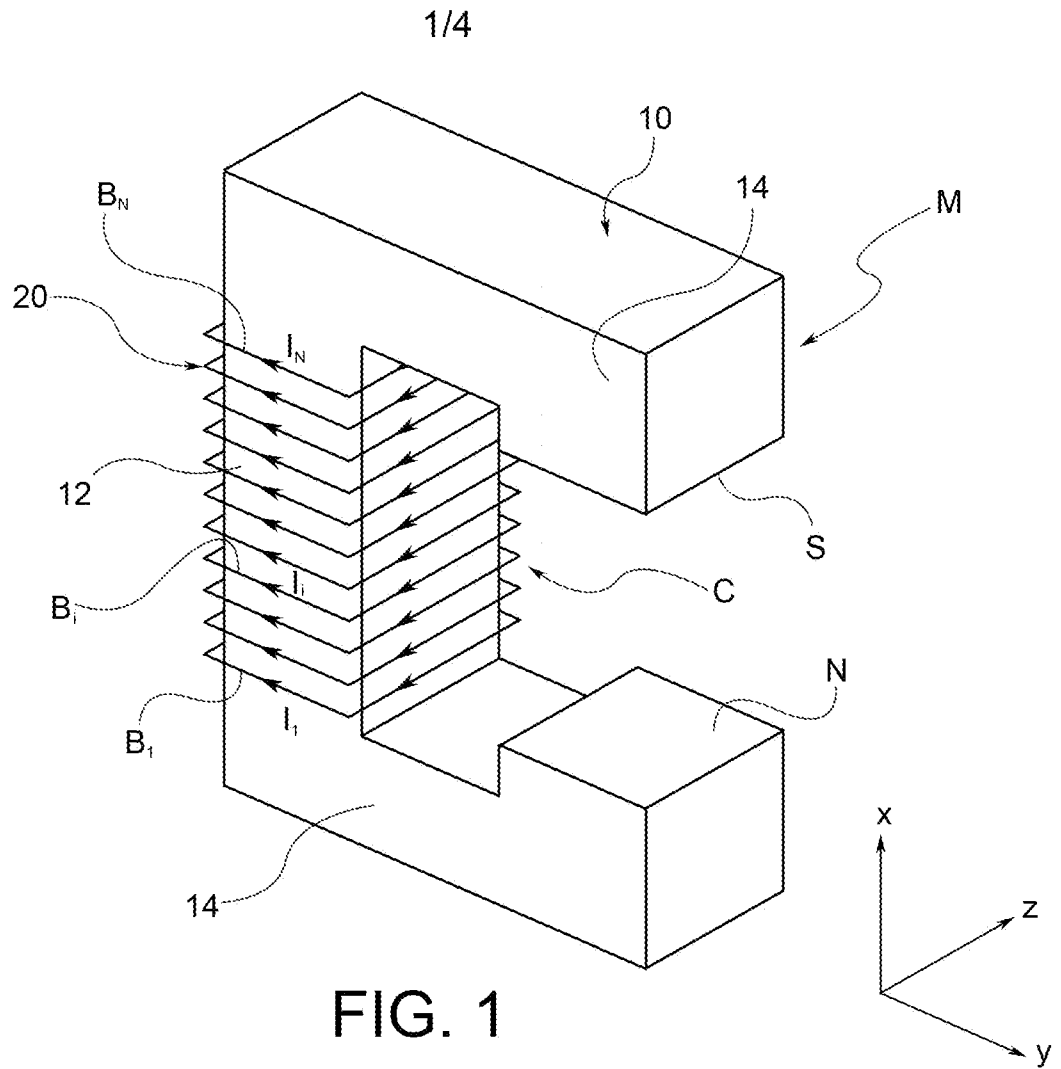
6. A magnetic assembly according to Claim 1 or 2, wherein the second source of field (20) includes a pair of planar coils (B'_1, B'_2) arranged side by side, each of which is wound around a respective lateral portion (14) of the magnetic structure of the first source of magnetic field (10).

7. A magnetic assembly according to Claim 1 or 2, wherein the second source of field (20) includes a pair of arrangements of planar coils, each arrangement comprising a plurality of planar coils ($B''_{1a}, \dots, B''_{1n}, B''_{2a}, \dots, B''_{2n}$) wound around a respective lateral portion (14) of the magnetic structure of the first source of magnetic field (10) according to a radial or fan arrangement, whereby each coil comprises a portion of the conductive path within the cavity, so as to form a two-dimensional distribution of current ($I''_{1a}, \dots, I''_{1n}, I''_{2a}, \dots, I''_{2n}$) adjacent to an even back wall (W) of said cavity (C).

8. A magnetic assembly according to Claim 1 or 2, wherein the second source of field (20) includes a pair of arrangements of planar coils, each arrangement comprising a plurality of planar coils ($B'''_{1a}, \dots, B'''_{1n}, B'''_{2a}, \dots, B'''_{2n}$) wound around a respective lateral portion of the magnetic structure of the first source of magnetic field (10) according to a stacked arrangement on parallel planes, whereby each coil comprises a portion of the conductive path within the cavity, so as to form a two-dimensional distribution of current ($I'''_{1a}, \dots, I'''_{1n}, I'''_{2a}, \dots, I'''_{2n}$) adjacent to a curved back wall (W) of said cavity (C).

9. A magnetic assembly according to any one of the preceding claims, comprising a pair of correcting lateral windings (B_C) for correction of the overall magnetic field generated by superposition of the contributions of said first and second source of field (10, 20), lying on surfaces which are coplanar or parallel to the poles (N, S).

10. An apparatus for magnetic resonance imaging, including a magnetic assembly (M) according to Claims 1 to 9.



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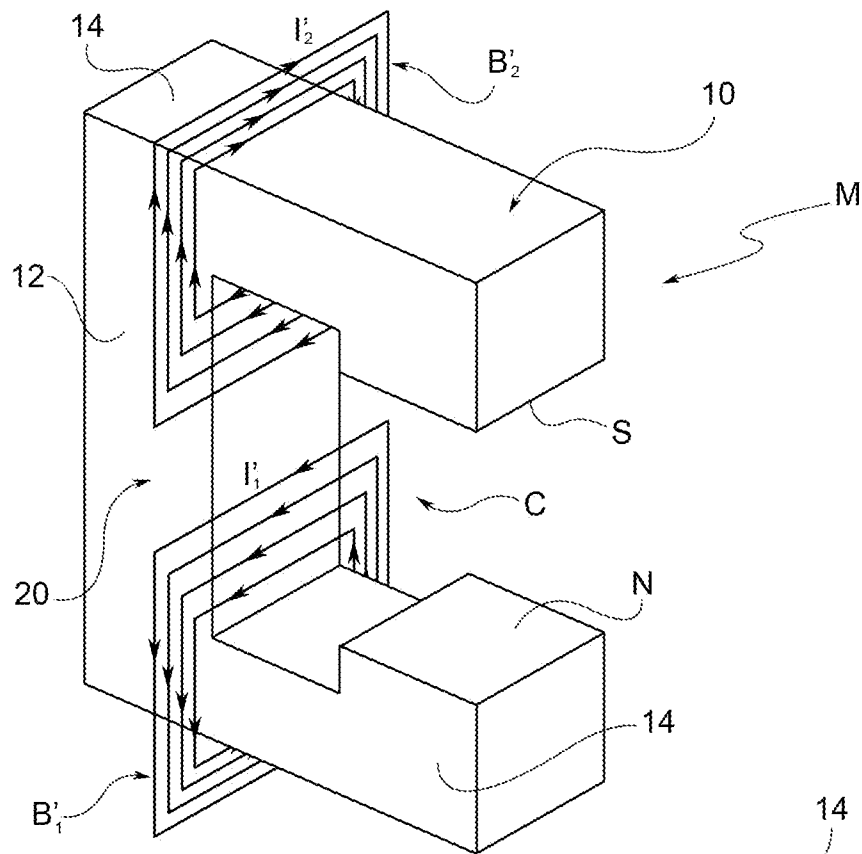


FIG. 3

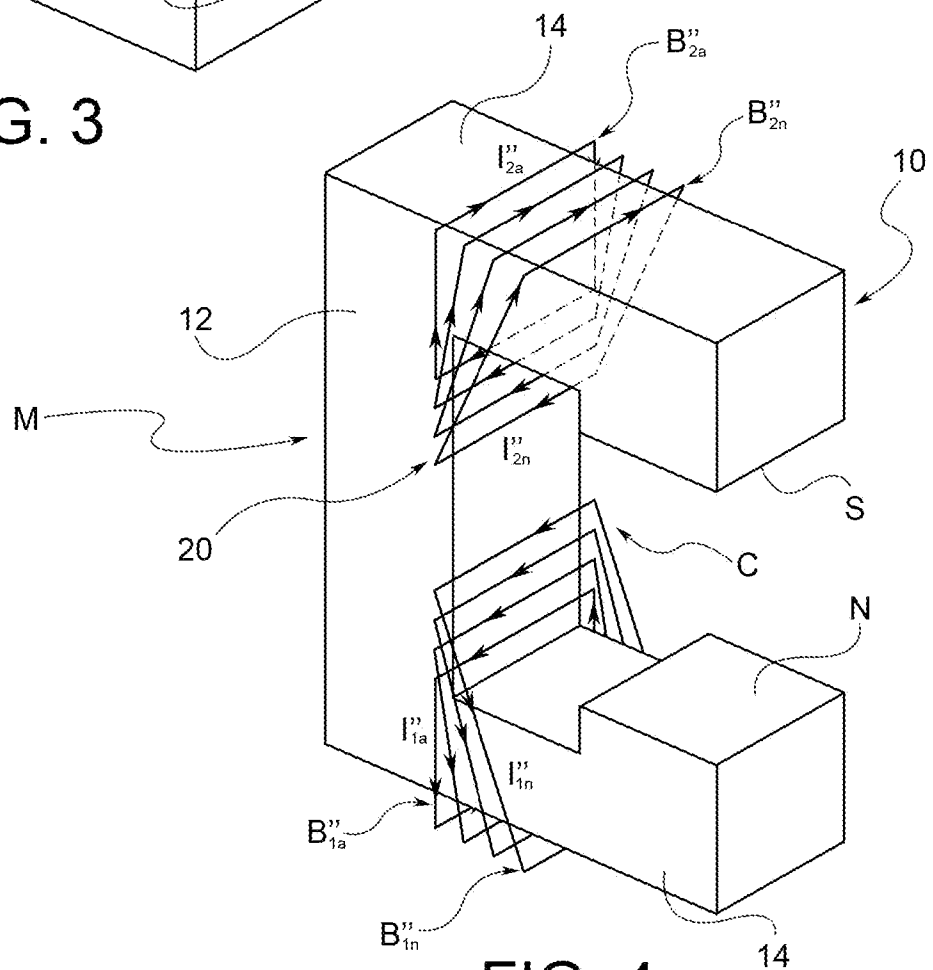


FIG. 4

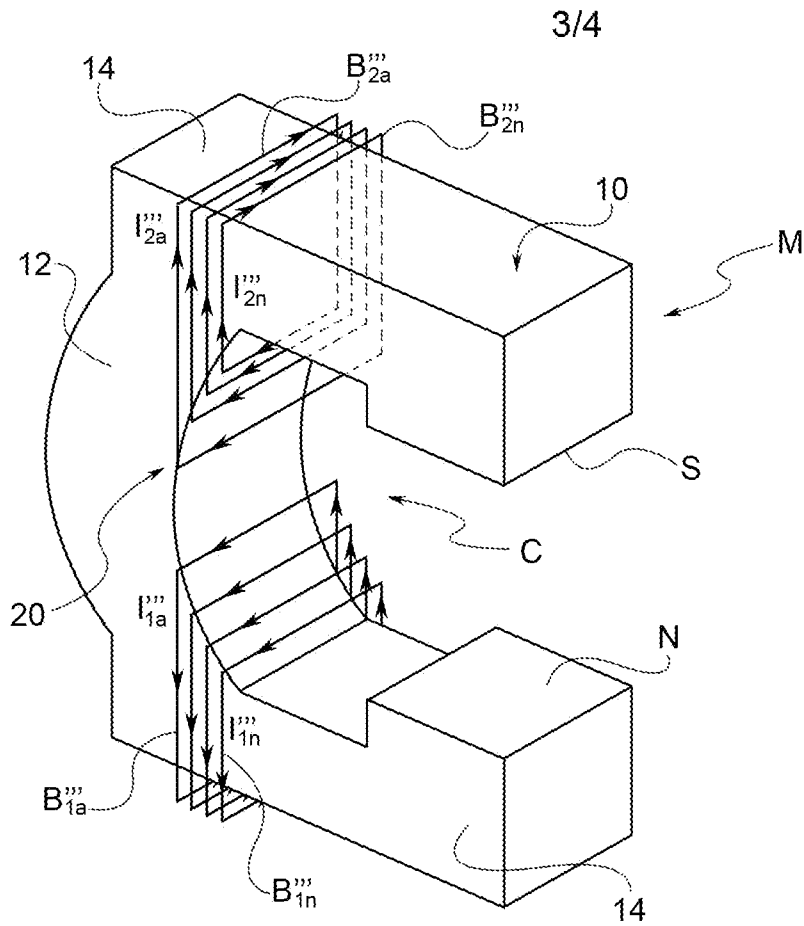


FIG. 5

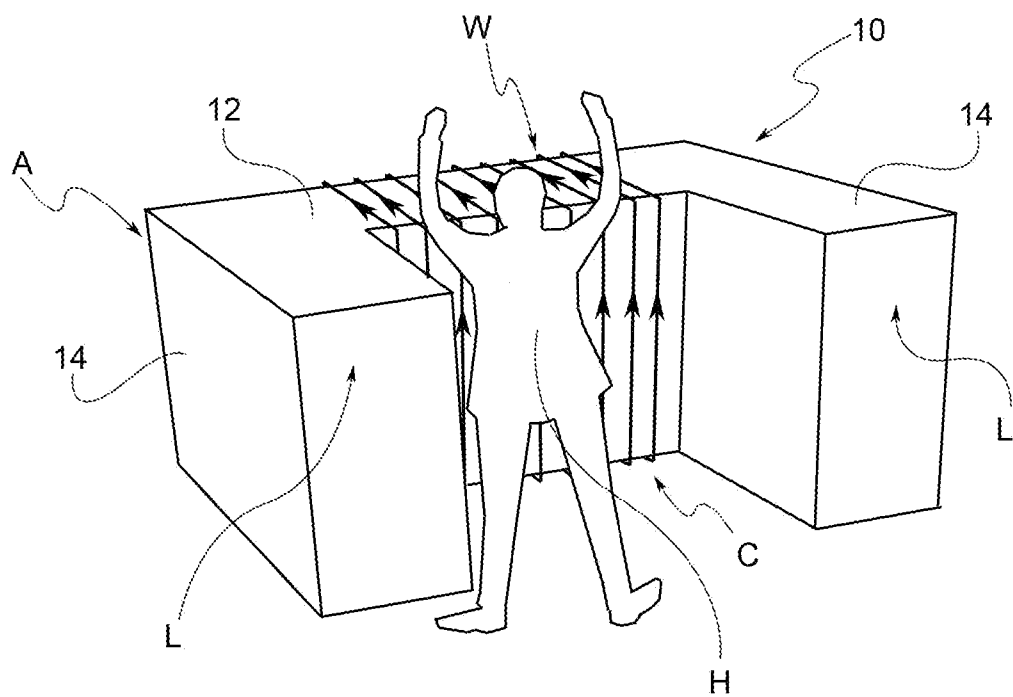


FIG. 6

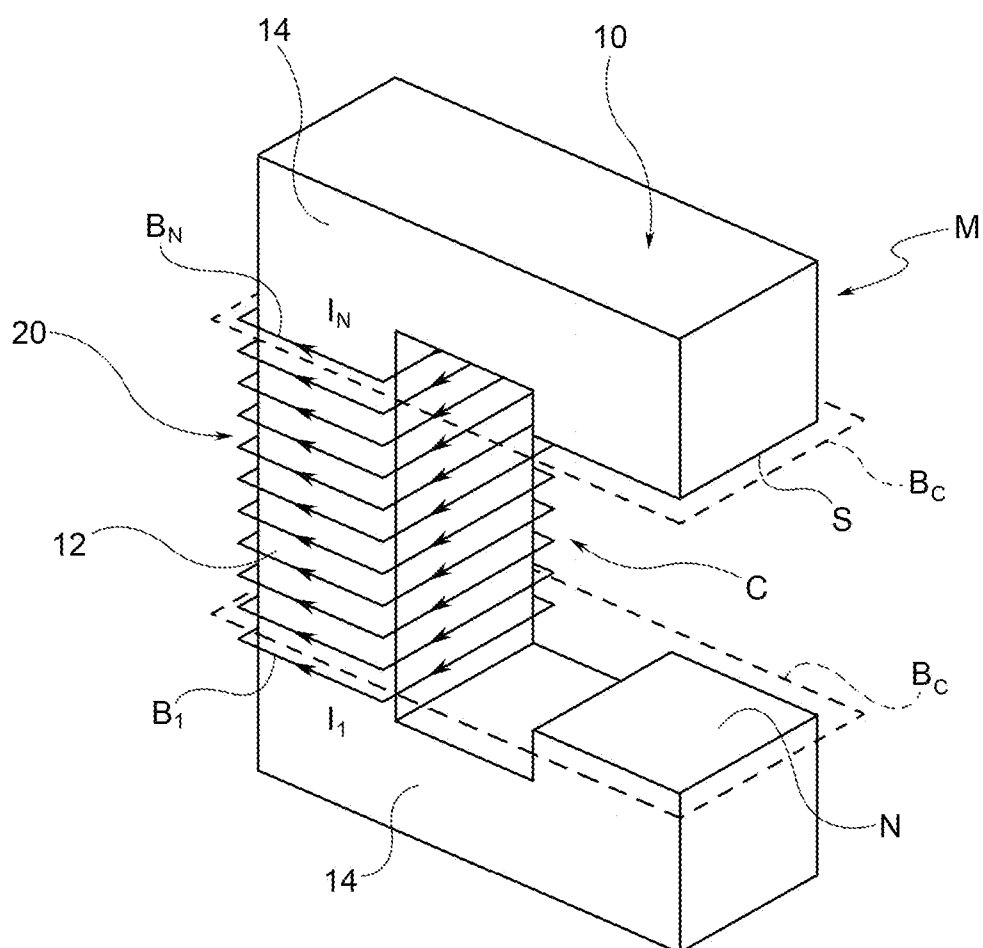


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2012/051557

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01R33/38 G01R33/3875
ADD.

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)

G01R

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)

EPO-Internal, INSPEC, BIOSIS, COMPENDEX, EMBASE, MEDLINE, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	column 2, line 38 - column 3, line 35	2,5,8
X	US 2002/105328 A1 (GOTO TAKAO [JP] ET AL) 8 August 2002 (2002-08-08) paragraphs [0001], [0010], [0076], [0077]; claim 1; figure 5	1,4,6,7, 9,10
X	JP 2004 105240 A (GE MED SYS GLOBAL TECH CO LLC) 8 April 2004 (2004-04-08) abstract	1,10
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☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

12 June 2012

Date of mailing of the international search report

25/06/2012

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INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2012/051557

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	BERTORA F ET AL: "Opening Compensation in a 1.5T Open MRI Magnet for the Functional Study of the Human Motor Cortex", IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY IEEE USA, vol. 20, no. 3, June 2010 (2010-06), pages 1831-1834, XP002662985, ISSN: 1051-8223 figure 1	2
Y	----- EP 0 913 699 A2 (PICKER INT INC [US] KONINKL PHILIPS ELECTRONICS NV [NL]) 6 May 1999 (1999-05-06) figure 1	8
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