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— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

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(54) Title: NANOPARTICLE RF SHIELD FOR USE IN AN MRI DEVICE

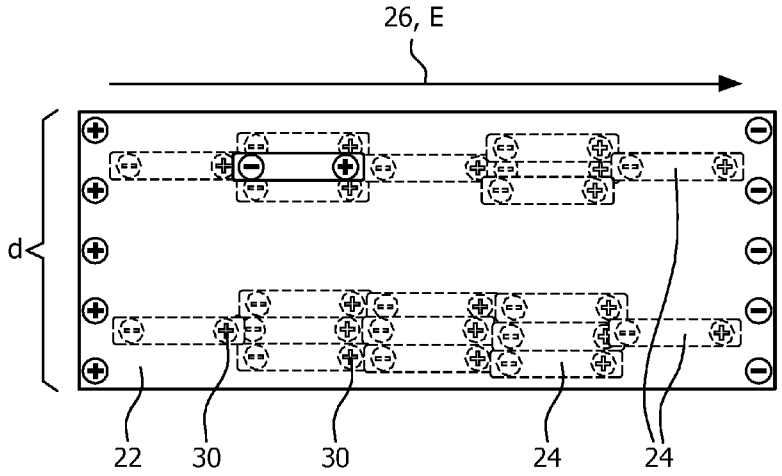


FIG. 3

(57) Abstract: A radio frequency (RF) shield for use in a magnetic resonance imaging (MRI) scanner, the RF shield comprising a carrier (22) and a plurality of nanoparticles (24) which - are immovably connected to the carrier (22), - are aligned along a direction (26) in space, and - have an anisotropic electrical conductivity in the direction (26) in space.

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NANOPARTICLE RF SHIELD FOR USE IN AN MRI DEVICE

FIELD OF THE INVENTION

The invention pertains to a nanoparticle radio frequency (RF) shield for use in an operative MR (Magnetic Resonance) scanner.

BACKGROUND OF THE INVENTION

In magnetic resonance (MR) imaging scanners, a static magnetic field (B_0) is used to align protons in a human body. A gradient magnetic field created by gradient coils may be superimposed to the static magnetic field, so that an obtained signal can be related to an exact location. The gradient magnetic field may be applied by using a pulse technique corresponding to frequencies f_{grad} of up to a few kHz. A so-called radio frequency (RF) coil is operated at radio wave frequencies f_{RF} typically between 10 MHz and 100 MHz, depending on the B_0 magnetic field strength, and a magnetic field strength B_1 to excite the protons or other nuclei of atoms in the human body that subsequently emit RF magnetic resonance signals. RF body coils are commonly used to combine RF transmission and magnetic resonance signal receiving in one device. For at least the reason of a prevention of signal noise in the RF body coil, a decoupling of the gradient coils and the RF body coil by an RF shield at radio frequencies between 10 MHz and 100 MHz is most desirable. Further, a sensitivity of the RF body coil with respect to its position relative to the gradient coils shall be maintained. As an object, the RF shield ideally should attenuate the radio frequency, but should be transparent to frequencies of the pulses of the gradient magnetic field.

In common solutions, electrically conductive plates, made for instance from copper-clad laminate, are furnished with slits such that eddy currents can be induced in the copper shield. These slits are bridged by capacitors, impedances of which are high at low frequencies and low at high frequencies, so that eddy currents cannot be induced for the low frequencies of the gradient coil, but for the high frequencies of the RF body coil.

In conventional RF shielding, illustrated in Fig. 1, an electrically conductive layer of some thickness is provided, in which the RF field generates the eddy currents by induction, which results in a magnetic field that is directed opposite to its cause, thus attenuating the RF field inside the conductive layer. For frequencies below a frequency f_1 that

is determined by the electrical conductivity of the layer material, no shielding of the magnetic field occurs (region A of Fig. 1).

Even when the penetration depth is smaller than the layer thickness longitudinal onset of eddy currents cause damping which is proportional to the logarithm of a ratio of the attenuated and the unattenuated RF power, is proportional to the frequency, up to a frequency f_2. At frequency f_2, the penetration depth becomes smaller than the thickness resulting in an exponentially increasing damping (on a logarithmic scale).

For achieving the object described above, it is required that at frequencies of the gradient magnetic field, the shielding should be within region A of the damping curve of Fig. 1, and for RF frequencies, the shielding should be within region C.

In other words: $f_{grad} \leq f_1$ and $f_{RF} \geq f_2$. Unfortunately, f_1 and f_2 are correlated in isotropic conducting materials, like metals, according to:

$f_1 = (\mu_0 \cdot \sigma \cdot d \cdot w)^{-1}$ and

$$f_2 = (\mu_0 \cdot \mu_r \cdot \sigma \cdot d^2)^{-1} = (f_1 \cdot w) / (\mu_r \cdot d)$$

where d denotes a thickness of the electrically conductive material, w a largest dimension of an RF shield, σ the electrical conductivity of the isotropic material, μ_0 the magnetic permeability of the vacuum and μ_r the relative magnetic permeability of the isotropic material. In MR imaging scanner applications, it is required that $\mu_r = 1$ to prevent distortion of the static magnetic field B_0, thus

$$f_2 / f_1 = w / d. \qquad \text{(eq. (I))}$$

Since the ratio f_2 / f_1 is predetermined by the MR scanner imaging application requirements as mentioned above, the ratio of dimensions w, which is given by the object to be shielded, and thickness d of the electrically conductive material, is fixed.

SUMMARY OF THE INVENTION

It is therefore an object of the invention to provide an RF shield that attenuates radio frequency waves that are used to excite protons or nuclei of atoms in a human body during an operation of an MR imaging scanner, and that at the same time, is transparent to a gradient magnetic field pulse. The phrase “transparent”, as used in this application, shall be

understood particularly such that an electromagnetic field is attenuated by the RF shield by less than 6 dB, preferably less than 3 dB in terms of power.

In one aspect of the present invention, the object is achieved by a radio frequency (RF) shield for use in a magnetic resonance (MR) imaging scanner, comprising a carrier and a plurality of nanoparticles, wherein, in a state of operation, the plurality of nanoparticles is immovably connected to the carrier and is aligned along a direction in space, and wherein the plurality of nanoparticles has an anisotropic electrical conductivity in the direction in space.

By making use of a plurality of nanoparticles having an anisotropic electrical conductivity in at least one direction, more design freedom is given for a lay-out of the RF shield, because via

$$f_1 = (\mu_0 \cdot \sigma_w \cdot d \cdot w)^{-1} \qquad \text{(eq. (II))}$$

wherein σ_w denotes an electrical conductivity in the direction of a largest dimension of an RF shield which may coincide with the direction of electrical anisotropic conductivity, and $f_2 = (\mu_0 \cdot \mu_r \cdot \sigma_d \cdot d^2)^{-1}$, wherein σ_d denotes an electrical conductivity in the direction of a thickness of the RF shield, and with $\mu_r=1$ (see above), it follows that

$$f_2 = f_1 \cdot (w / d) \cdot (\sigma_w / \sigma_d). \qquad \text{(eq. (III))}$$

The ratio σ_w / σ_d may represent a degree of the anisotropy of the electrical conductivity in the two directions. The higher the ratio σ_w / σ_d, the larger an RF shield can be provided at a given thickness d.

In another aspect of the present invention, the carrier essentially encompasses the plurality of nanoparticles, thus providing a protective environment for the electrically conductive plurality of nanoparticles in a mechanically stable arrangement.

In a further aspect of the invention, the carrier has an electrical conductivity that is substantially lower than the anisotropic electrical conductivity of the plurality of nanoparticles. With the electrical conductivity of the carrier being negligible in comparison to the anisotropic electrical conductivity of the plurality of nanoparticles, design options provided for the RF shield will not be affected.

In a preferred embodiment, the direction in space in at least one contiguous portion is a curved line that essentially completely lies in a plane. An alignment like this may

allow for an effective attenuation of an RF field directed in a direction that is perpendicular to the curved line, while the RF shield may be transparent to other RF field directions at the same time. The curved line may represent at least a portion of a circular arc or a complete circle. The curved line may also represent another closed figure in the plane, like an ellipse. The term "curved line" may also include closed polygons with rounded corners.

In another aspect of the invention, the carrier is essentially made from a plastic polymer. Plastic polymer carriers may be of light-weight design and may provide a low-cost solution of the protective environment for the nanoparticles. Preferably, the plastic polymer is one of the group of thermoplastic materials which the one of skills in the art is familiar with. Thereby, a number of well-known production methods applicable to thermoplastics, such like injection or compression molding, may become available for a production of the RF shield.

In a preferred embodiment, the anisotropic electrical conductivity of the plurality of nanoparticles can be represented by a tensor having eigenvalues that differ by a factor of at least 50. Such a degree of anisotropy in electrical conductivity may give rise to a large number of design options for the RF shield.

In yet another aspect of the invention, the nanoparticles are selected from a group of materials consisting of carbon nanotubes, carbon fibers, and graphene. The phrase "graphene", as used in this application, shall be understood particularly as an allotrope of carbon formed by a one-atom-thick planar sheet of carbon atoms that are arranged in a honeycomb crystal lattice. The carbon nanotubes that are familiar to the one of skills in the art shall be understood to comprise single-walled nanotubes (SWNT) as well as multi-walled nanotubes (MWNT). Nanoparticles selected from this group of materials show an intrinsic anisotropic electrical conductivity and may have the potential to be usable for an RF shield which has an anisotropic electrical conductivity in at least one direction.

In a preferred embodiment, the nanoparticles are furnished with at least one electrical dipole member to create a permanent electrical dipole moment. Nanoparticles with a permanent electrical dipole moment may allow for a creation of an anisotropic electrical conductivity in at least one direction by maintaining an alignment of the nanoparticles during a curing state of production of an RF shield by applying an external electrical field. Preferably, heteroatoms such as nitrogen or boron may be used as electrical dipole members.

In yet another preferred embodiment, the nanoparticles may be furnished with a permanent magnetic dipole member to create a permanent magnetic dipole which may provide advantageous options for an alignment of the nanoparticles by applying an external

magnetic field during the production of an RF shield. Preferred permanent magnetic dipole members may be iron oxide Fe_xO_y or ferrites, such as barium ferrite $BaO \cdot 6Fe_xO_y$.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter. Such embodiment does not necessarily represent the full scope of the invention, however, and reference is made therefore to the claims and herein for interpreting the scope of the invention.

In the drawings:

Fig. 1 shows a simplified view of a shield damping curve,

Fig. 2 illustrates an RF shield in accordance with the invention, arranged in a coil arrangement of an MR scanner,

Fig. 3 is a simplified cross-sectional view of the RF shield according to Fig. 2, and

Fig. 4 illustrates another embodiment of an RF shield in accordance with the invention.

DETAILED DESCRIPTION OF EMBODIMENTS

Fig. 1 shows a simplified view of a shield damping curve that has partially been already discussed in the introduction. A typical value for a ratio of cutoff-frequencies f_2 and f_1 of an RF shield to be applied in eq. (III) is $f_2/f_1 = 100$ MHz / 1 kHz = 10^5. For a material of isotropic electrical conductivity, this would also be the ratio of an RF shield dimension w and a thickness d, according to eq. (I).

For a material with an anisotropic electrical conductivity, however, a constraint for feasible design options is given by the fact that by eq. (III), the ratio of the cutoff-frequencies f_1, f_2 has to equal a product of a ratio of the RF shield dimension w and the thickness d, and a ratio of electrical conductivities σ_w and σ_d of the RF shield (Fig. 2) in directions that are aligned with the RF shield dimension w and the thickness d, respectively. Although equation (III) seems to imply that only the ratio of the RF shield dimension w and the thickness d is of importance, it should be noted here that a certain absolute thickness d is required to obtain a desired absolute value for f_1 by equation (II), so that the thickness d cannot be made small at discretion to fulfill equation (III).

Thus, when a ratio of the electrical conductivities σ_w and σ_d of 50 can be achieved, the RF shield dimension w needs to be as large as two thousand times the thickness

d. If the required thickness d was 0.5 mm, this results in an RF shield dimension w of 1000 mm.

Illustrated in Fig. 2 is a simplified lateral cross-sectional view of a coil arrangement of a magnetic resonance (MR) scanner 10. The MR scanner 10 comprises a main magnet 12 to create a static magnetic field B_0. The main magnet 12 provides an imaging volume 14 for a patient, in which the static magnetic field B_0 is essentially homogenous and directed along a straight direction which is commonly referred to as the z-axis 28. The MR scanner 10 furthermore comprises gradient coils 16 to generate a gradient magnetic field. The gradient coils 16 are arranged between the main magnet 12 and the imaging volume 14 and are provided to be operated by current pulses having a bandwidth of 3 kHz. Further, an RF body coil 18 is provided to transmit RF waves of RF magnetic field strength B_1, and to subsequently receive RF signals from excited nuclei within the imaging volume 14. The RF body coil 18 is disposed between the gradient coil 16 and the imaging volume 14.

In order to electromagnetically decouple the gradient coils 16 and the RF body coil 18, an RF shield shaped as a hollow cylinder 20 is arranged concentrically to the gradient coils 16 and between the gradient coils 16 and the RF body coil 18. The RF shield comprises a carrier 22 made from thermoplastic polymer polyamide (Fig. 3). In a state of operation inside the MR scanner 10, the hollow cylinder 20 comprises a plurality of nanoparticles 24 that is immovably connected to the carrier 22 such that the carrier 22 completely encompasses each nanotube of the plurality of nanotubes; thus providing mechanical protection and stability.

The plurality of nanoparticles 24 is aligned along a direction 26 in space which is a straight line parallel to the z-axis 28 through a center of the imaging volume 14, wherein the z-axis 28 is arranged parallel to the static magnetic field B_0.

The nanoparticles 24 of the plurality of nanoparticles 24 are formed by (single-walled) carbon nanotubes. These carbon nanotubes have a metal-like electrical conductivity along a direction of extension which coincides with the direction 26 of alignment. In directions perpendicular to the direction of alignment 26, an electrical conductivity of the plurality of carbon nanotubes is lower by a factor of at least 1000. Along the direction of alignment 26, individual nanotubes overlap and may contact adjacent nanotubes which results in a high electrical conductivity in the direction 26 of alignment, so that the plurality of nanoparticles 24 has an anisotropic electrical conductivity in this direction 26.

To obtain a proper alignment of the plurality of nanotubes, each individual carbon nanotube has been furnished with electrical dipole members 30 to create a permanent electrical dipole moment. By applying an external electric field E in a phase during production of the RF shield in which the plastic polymer is in a softened or even liquid state, thus allowing a change of orientation of the electrical dipoles, and by maintaining the external electric field E until the plastic polymer hardens, a uniform alignment may be attained as shown in Fig. 3. The electrical dipole members are formed by boron heteroatoms, each of the nanotubes has been doped with. Due to the lower electronegativity of boron atoms in comparison to carbon atoms, a center of the electric charge of binding electrons is shifted towards the carbon atom, resulting in a permanent electric dipole configuration of the nanotubes.

A mathematical description of the electrical conductivity of the plurality of nanotubes may be provided by a 3 x 3–tensor. In a suitably selected coordinate system, this tensor would be a diagonal matrix, with the diagonal elements being the eigenvalues of the electrical conductivity in the directions of the selected coordinate system. The tensor that represents the anisotropic electrical conductivity of the plurality of carbon nanotubes of the RF shield has eigenvalues that thereby differ by a factor of about 1000.

An electrical conductivity of the carrier is lower than the anisotropic electrical conductivity of the plurality of nanotubes by several orders of magnitude, so that the electrical conductivity of the hollow cylinder 20 is, for practical purposes, completely ruled by that of the aligned nanotubes.

The RF wave that is emitted by the RF body coil 18 has a magnetic field strength B_1 and is essentially directed perpendicular to the static magnetic field B_0 and the gradient field. Thereby, eddy currents are being induced in the RF shield in the direction of alignment 26 of the nanotubes, attenuating the field strength B_1 as their cause of generation. No eddy currents are induced by the magnetic gradient field pulses, as the electrical conductivity of the plurality of nanoparticles 24 in directions perpendicular to the direction of alignment 26 is low.

Another embodiment of an RF shield in accordance with the invention is illustrated in Fig. 4. Fig. 4 shows the RF shield formed as a shielding box 32 for shielding an RF coil electronic unit 34 from the RF transmit field generated by the RF body coil 18 (or local RF transmit coils) of the MR scanner 10, and, vice versa, shielding the RF body coil 18 (and other RF receive coils) from spurious signals generated by the RF coil electronic unit 34. In the state of operation, the RF coil electronic unit 34 is placed inside the shielding box

32. For this application, the shielding effectiveness has to be much higher than for the RF shield of the first embodiment, while for magnetic gradient field frequencies f_{grad} the shielding box 32 still has to be transparent.

The shielding box 32 comprises a carrier 38 made from the injection-moldable thermoplastic acrylonitrile butadiene styrene (ABS), and a plurality of nanoparticles formed by silver-coated carbon nanotubes 40. By the injection molding process, the plurality of nanoparticles is immovably connected to the carrier 38 after the ABS thermoplastic hardens. The silver-coated carbon nanotubes 40 are aligned in parallel to a shorter edge for each of the six faces of the shielding box, respectively. Due to an anisotropic electrical conductivity of the nanoparticles in a direction of alignment 36, eddy currents can be generated in the shielding box 32 to attenuate the RF field, while at the same time, it is transparent to the gradient field frequency f_{grad} in the region of a few kHz.

While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing 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 measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

REFERENCE SYMBOL LIST:

10	MR imaging scanner	f_{RF}	radio wave frequency
12	main magnet	σ_d	electrical conductivity
14	imaging volume	σ_w	electrical conductivity
16	gradient coil	w	shield dimension
18	RF body coil	B_0	static magnetic field
20	hollow cylinder	B_1	RF magnetic field
22	carrier	E	external electric field
24	nanoparticle		
26	direction of alignment		
28	z-axis		
30	electrical dipole member		
32	shielding box		
34	electronic unit		
36	direction of alignment		
38	carrier		
40	silver-coated nanotube		
d	thickness		
f_1	cutoff-frequency		
f_2	cutoff-frequency		
f_{grad}	magnetic gradient field frequency		

CLAIMS:

1. A radio frequency (RF) shield for use in a magnetic resonance (MR) imaging scanner (10), comprising:

- a carrier (22; 38),
- a plurality of nanoparticles (24),

wherein, in a state of operation, the plurality of nanoparticles (24) is immovably connected to the carrier (22; 38) and is aligned along a direction (26; 36) in space, and
wherein the plurality of nanoparticles (24) has an anisotropic electrical conductivity in the direction (26; 36) in space.

2. The radio-frequency (RF) shield as claimed in claim 1, wherein the carrier (22; 38) essentially encompasses the plurality of nanoparticles (24).

3. The radio-frequency (RF) shield as claimed in claim 1, wherein the carrier (22; 38) has an electrical conductivity that is substantially lower than the anisotropic electrical conductivity σ_d, σ_w of the plurality of nanoparticles (24).

4. The radio-frequency (RF) shield as claimed in claim 1, wherein the direction (26; 36) in space in at least one contiguous portion is a curved line that essentially completely lies in a plane.

5. The radio-frequency (RF) shield as claimed in claim 1, wherein the carrier (22; 38) is essentially made from a plastic polymer.

6. The radio-frequency (RF) shield as claimed in claim 1, wherein the anisotropic electrical conductivity σ_d, σ_w can be represented by a tensor having eigenvalues that differ by a factor of at least 50.

7. The radio-frequency (RF) shield as claimed in claim 1, wherein the nanoparticles (24) are selected from a group of materials consisting of carbon nanotubes, carbon fibers, and graphene.

8. The radio-frequency (RF) shield as claimed in claim 7, wherein the nanoparticles (24) are furnished with at least one electrical dipole member (30) to create a permanent electrical dipole moment.

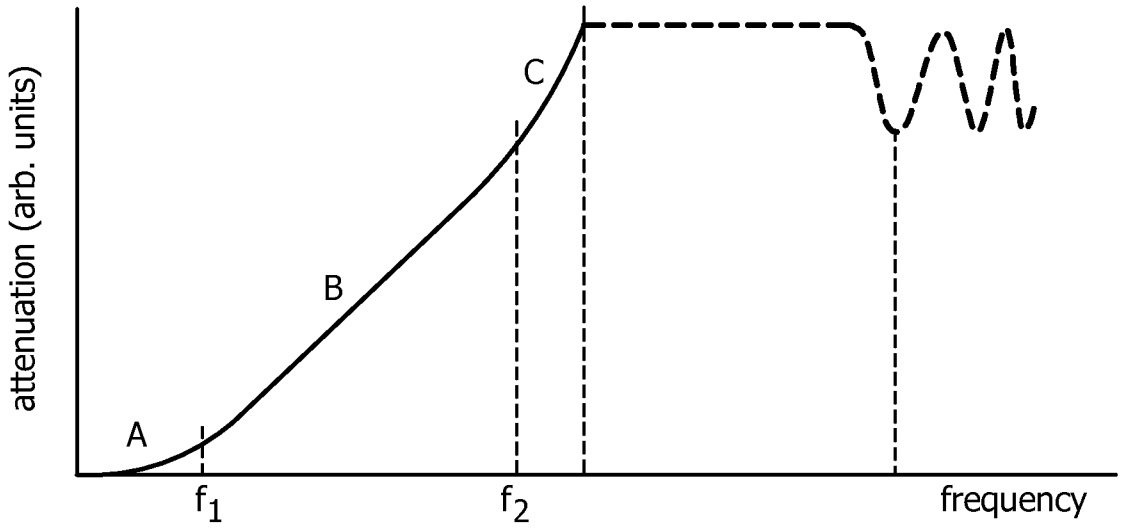

attenuation (arb. units)
A
B
C
f_1
f_2
frequency

FIG. 1

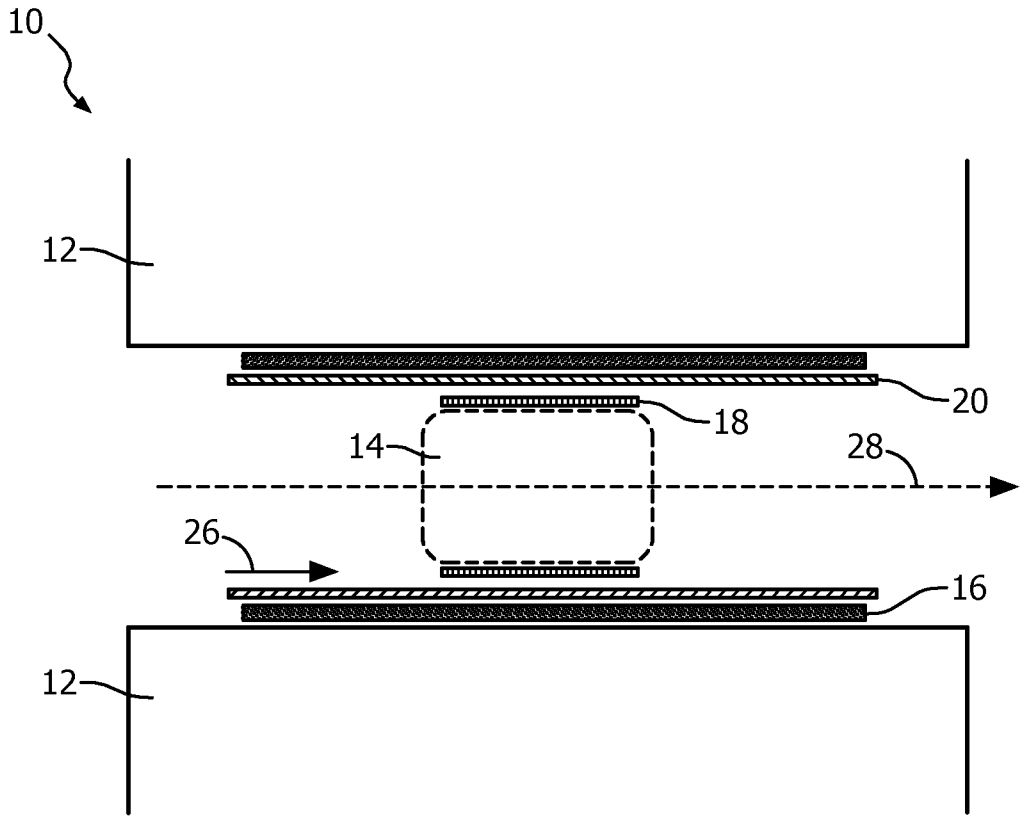

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FIG. 2

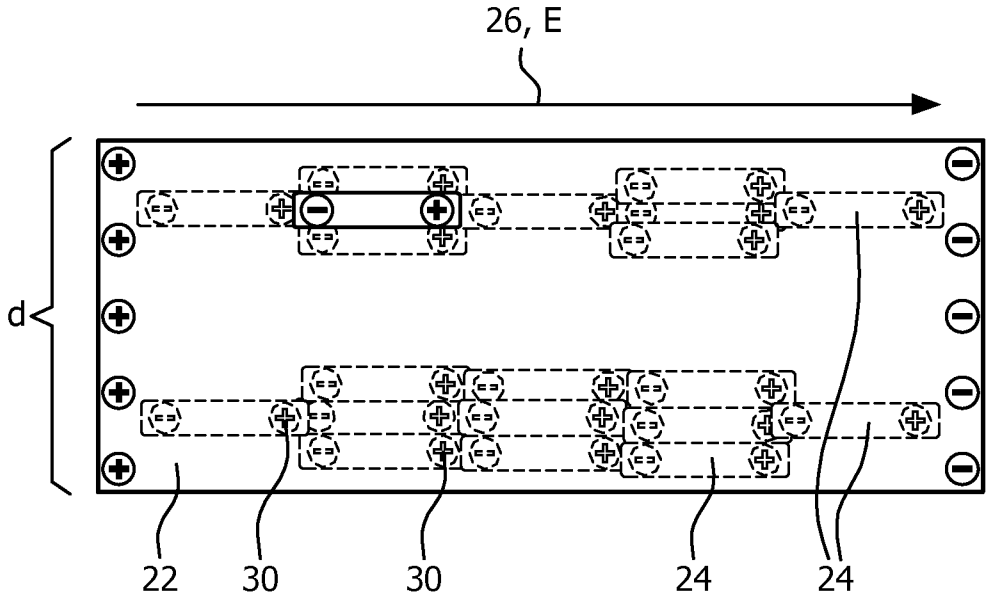


FIG. 3

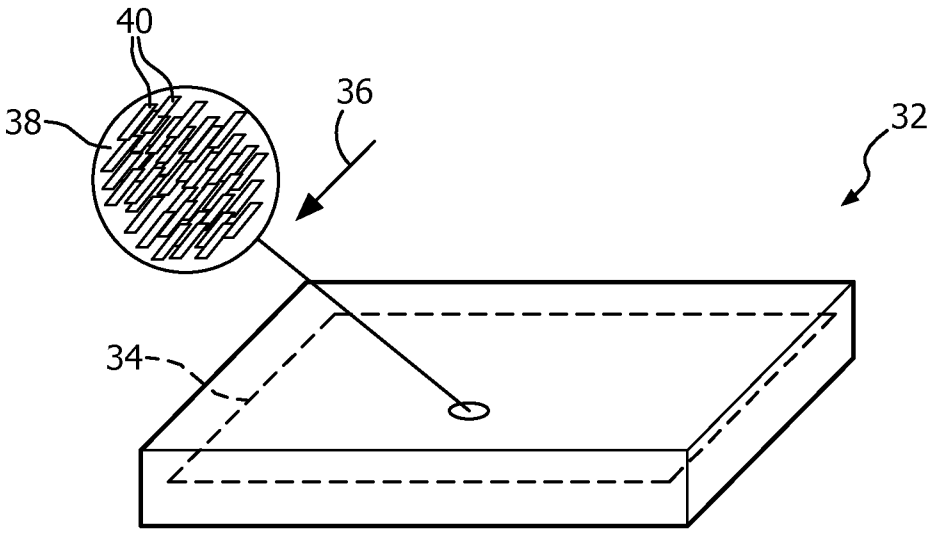


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/050738

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R33/422
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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008/023010 A1 (INMAN D MICHAEL [US] ET AL) 31 January 2008 (2008-01-31) paragraphs [0003] - [0011], [0022] - [0034]; figures 1-6	1-7
X	US 2010/219383 A1 (EKLUND PETER C [US]) 2 September 2010 (2010-09-02) paragraphs [0002] - [0011], [0021] - [0041], [0066] - [0067], [0206] - [0212], [0221]	1-8

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 April 2013	08/05/2013

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/050738

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DAI S G ET AL: "Effect of carbon-fiber orientation on the EM shielding for the plastic laser module packages", 2002 PROCEEDINGS 52ND. ELECTRONIC COMPONENTS AND TECHNOLOGY CONFERENCE. ECTC 2002. SAN DIEGO, CA, MAY 28 - 31, 2002; [PROCEEDINGS OF THE ELECTRONIC COMPONENTS AND TECHNOLOGY CONFERENCE], NEW YORK, NY : IEEE, US, vol. CONF. 52, 28 May 2002 (2002-05-28), pages 1675-1679, XP010747863, DOI: 10.1109/ECTC.2002.1008333 ISBN: 978-0-7803-7430-0	1-7
Y	the whole document	8

X	WO 2010/124260 A1 (LOCKHEED CORP [US]; SHAH TUSHAR K [US]; ALBERDING MARK R [US]; MALECKI) 28 October 2010 (2010-10-28) paragraphs [0003] - [0008], [0035] - [0037], [0046], [0048], [0051] - [0054], [0095] - [0113]; figures 7-10	1-8

X	JOU W S ET AL: "THE INFLUENCE OF FIBER ORIENTATION ON ELECTROMAGNETIC SHIELDING IN LIQUID-CRYSTAL POLYMERS", JOURNAL OF ELECTRONIC MATERIALS, WARRENDALE, PA, US, vol. 31, no. 3, 1 March 2002 (2002-03-01), pages 178-184, XP009006044, ISSN: 0361-5235	1-7
Y	the whole document	8

X	WERN-SHIARNG JOU ET AL: "A Carbon Nanotube Polymer-Based Composite with High Electromagnetic Shielding", JOURNAL OF ELECTRONIC MATERIALS, vol. 35, 1 January 2006 (2006-01-01), pages 462-470, XP55061035,	1-7
Y	the whole document	8

X	US 2007/036709 A1 (LASHMORE DAVID S [US] ET AL) 15 February 2007 (2007-02-15) paragraphs [0002] - [0015], [0068] - [0077]	1-8

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INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/050738

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	YANG S ET AL: "Electromagnetic interference shielding effectiveness of carbon nanofiber/LCP composites", COMPOSITES PART A: APPLIED SCIENCE AND MANUFACTURING, ELSEVIER SCIENCE PUBLISHERS B.V., AMSTERDAM, NL, vol. 36, no. 5, 1 May 2005 (2005-05-01), pages 691-697, XP027846591, ISSN: 1359-835X [retrieved on 2005-05-01]	1-7
Y	the whole document	8

X	KIM Y A ET AL: "Fabrication of aligned carbon nanotube-filled rubber composite", SCRIPTA MATERIALIA, ELSEVIER, AMSTERDAM, NL, vol. 54, no. 1, 1 January 2006 (2006-01-01), pages 31-35, XP027890420, ISSN: 1359-6462 [retrieved on 2006-01-01]	1-7
Y	the whole document	8

X	US 2003/036776 A1 (FOSTER THOMAS H [US] ET AL) 20 February 2003 (2003-02-20) paragraphs [0005] - [0008], [0033] - [0035]; figure 1	1-7

Y	MA ET AL: "Alignment and dispersion of functionalized carbon nanotubes in polymer composites induced by an electric field", CARBON, ELSEVIER, OXFORD, GB, vol. 46, no. 4, 1 February 2008 (2008-02-01), pages 706-710, XP022542583, ISSN: 0008-6223, DOI: 10.1016/J.CARBON.2008.01.019 the whole document	8

A	LIANG J ET AL: "Electromagnetic interference shielding of graphene/epoxy composites", CARBON, ELSEVIER, OXFORD, GB, vol. 47, no. 3, 1 March 2009 (2009-03-01), pages 922-925, XP025898551, ISSN: 0008-6223, DOI: 10.1016/J.CARBON.2008.12.038 [retrieved on 2008-12-27] the whole document	1-8

	-/--	

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/050738

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	VARRLA ESWARAIAH ET AL: "Functionalized Graphene-PVDF Foam Composites for EMI Shielding", MACROMOLECULAR MATERIALS AND ENGINEERING, vol. 296, no. 10, 3 June 2011 (2011-06-03) , pages 894-898, XP55061038, ISSN: 1438-7492, DOI: 10.1002/mame.201100035 the whole document	1-8
A	HONE J ET AL: "Electrical and thermal transport properties of magnetically aligned single wall carbon nanotube films", APPLIED PHYSICS LETTERS, AIP, AMERICAN INSTITUTE OF PHYSICS, MELVILLE, NY, US, vol. 77, no. 5, 31 July 2000 (2000-07-31), pages 666-668, XP012027153, ISSN: 0003-6951, DOI: 10.1063/1.127079 the whole document	1-8
A	B.J. PENG ET AL: "Effective RF shielding with carbon fiber composites for simultaneous PET/MRI", PROC.INTL.SOC.MAG.RESON.MED. 17, 1 January 2009 (2009-01-01), page 3085, XP55061040, the whole document	1,7
A	KIM I T ET AL: "Anisotropic conductivity of magnetic carbon nanotubes embedded in epoxy matrices", CARBON, ELSEVIER, OXFORD, GB, vol. 49, no. 1, 1 January 2011 (2011-01-01), pages 54-61, XP027450915, ISSN: 0008-6223, DOI: 10.1016/J.CARBON.2010.08.041 [retrieved on 2010-08-25] see chapters 1; 3.4; 3.5	8
A	S. GEETHA ET AL: "EMI shielding: Methods and materials-A review", JOURNAL OF APPLIED POLYMER SCIENCE, vol. 112, no. 4, 15 May 2009 (2009-05-15), pages 2073-2086, XP55061041, ISSN: 0021-8995, DOI: 10.1002/app.29812 see pages 2073-2079	1-8
A	US 2010/280584 A1 (JOHNSON ROBERT SHAWN [US] ET AL) 4 November 2010 (2010-11-04) paragraphs [0002] - [0015], [0019] - [0024], [0090]; figure 8	1-7

-/--

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/050738

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2007/071957 A1 (ATKINS ANDREW F [GB] ET AL) 29 March 2007 (2007-03-29) paragraphs [0001] - [0007], [0054] - [0061]	1-3,5,7

Form PCT/ISA/210 (continuation of second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2013/050738

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2008023010 A1	31-01-2008	NONE	
US 2010219383 A1	02-09-2010	EP 2144845 A2	20-01-2010
		JP 2010520148 A	10-06-2010
		US 2010219383 A1	02-09-2010
		WO 2008140649 A2	20-11-2008
WO 2010124260 A1	28-10-2010	AU 2010238610 A1	27-10-2011
		AU 2010259173 A1	27-10-2011
		CA 2758568 A1	28-10-2010
		CA 2758570 A1	16-12-2010
		CN 102458825 A	16-05-2012
		CN 102461361 A	16-05-2012
		EP 2421702 A1	29-02-2012
		EP 2422595 A1	29-02-2012
		JP 2012524685 A	18-10-2012
		JP 2012525012 A	18-10-2012
		KR 20120017034 A	27-02-2012
		KR 20120023640 A	13-03-2012
		US 2010270069 A1	28-10-2010
		US 2010271253 A1	28-10-2010
		WO 2010124260 A1	28-10-2010
		WO 2010144183 A1	16-12-2010
US 2007036709 A1	15-02-2007	AU 2006345024 A1	27-03-2008
		CA 2616151 A1	28-01-2007
		EP 1926846 A2	04-06-2008
		EP 2365117 A1	14-09-2011
		JP 4864093 B2	25-01-2012
		JP 2009509066 A	05-03-2009
		US 2007036709 A1	15-02-2007
		US 2009215344 A1	27-08-2009
		US 2011316183 A1	29-12-2011
		WO 2008036068 A2	27-03-2008
US 2003036776 A1	20-02-2003	NONE	
US 2010280584 A1	04-11-2010	NONE	
US 2007071957 A1	29-03-2007	CN 1784300 A	07-06-2006
		EP 1620255 A1	01-02-2006
		GB 2401346 A	10-11-2004
		JP 2006525147 A	09-11-2006
		US 2007071957 A1	29-03-2007
		WO 2004098870 A1	18-11-2004