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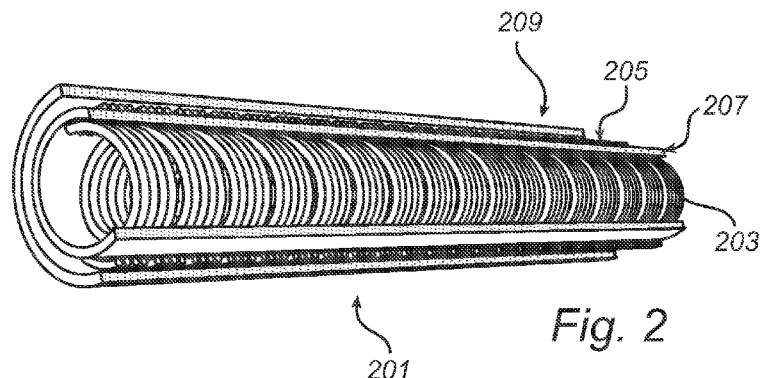
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(57) Abstract: The present invention relates to a medical implantable lead, comprising an elongate conductor enclosed by an elongate enclosing body, wherein the elongate enclosing body comprises an insulating material doped with particles of a conducting material, which particles are dispersed in the insulating material. The conducting material is chosen from a group of conducting materials which are able to provide percolation. The enclosing body causes a frequency dependent loss of signal energy of signals propagating along the conductor. A doping concentration of the conducting material is chosen such that the loss of energy of a utility signal is negligible, and the loss of energy of a radio frequency signal is significant within a frequency interval covering the frequency of an electro magnetic radio frequency field originating from a Magnetic Resonance Imaging apparatus.



MRI-safe medical implantable lead comprising an enclosing body doped with particles of a conducting material

FIELD OF THE INVENTION

The present invention relates to a medical implantable lead having an elongate conductor extending through an elongate enclosing body, wherein the elongate enclosing body comprises an insulating material doped with particles of a
5 conducting material, which particles are uniformly dispersed in the insulating material.

BACKGROUND OF THE INVENTION

A medical implantable lead has an elongated structure and comprises at least
10 one conductor and at least one enclosing body, typically an insulator. There are different lead structures, such as one conductor enclosing one insulator; two conductors arranged coaxially with a first insulator between them, i.e. the first insulator enclosing the inner conductor, and a second insulator enclosing the outer conductor; and two or more conductors extending in parallel enclosed by a common
15 insulator. A Magnetic Resonance Imaging (MRI) device, such as an MRI scanning equipment, is of great use for generating an image of the internal tissues of a human body. However, for persons who have a medical implantable lead implanted in their body, there are problems with induced currents in the medical implantable lead which may cause, in turn, heating of the lead, in particular the distal tip of the
20 lead. The MRI is based on Nuclear Magnetic Resonance (NMR) for protons of hydrogen nuclei. It is well known that all nuclei have spins which are randomly oriented. When a magnetic field is applied, the proton spins become either parallel or anti-parallel, and the energy levels are split into a higher level for the anti-parallel spin and a lower level for the parallel spin. Furthermore, the protons start precessing
25 around the magnetic field direction at a precession frequency (Larmor frequency) which is proportional to the magnetic field, and at a precession angle, which is also called flip angle. The MRI device additionally emits an external pulsed RF (Radio Frequency) signal, called RF field, which is an electro magnetic field. When the RF field is additionally applied, at Larmor frequency, protons from the lower energy level
30 with parallel spin will be excited to the higher energy level. This implies that the precession angle will change and all protons will precess in phase. After some time

(in the order of ms) the protons start to relax, that is the protons in the higher anti-parallel spin level will fall back to the lower parallel level, which implies that the precession angle falls back to the original value, and at the same time the protons will also de-phase. Both these processes will proceed with slightly different time-constants. The MRI takes advantage of the relaxation and time-constants to identify the substances in a human body. In-vitro MRI experiments have shown that the implanted medical lead acts like an antenna and receives the RF field of the MRI device. Consequently, considered from a field view, the MRI device generates an RF field, and a medical implantable lead subjected to the RF field absorbs RF energy from the RF field. The reception of the RF energy at the lead results in an RF wave propagating along the lead and heating the lead tip to an unacceptable level. Some other parts of the lead become heated as well, although not as much as the tip. Additionally, corresponding currents and voltages induced in the lead may be harmful as such, to the implanted device connected with the lead as well as to the person.

As mentioned above, the precession frequency is proportional to the magnetic field, and more particularly at 42.58 MHz/T. Currently, most MRI devices operate at 1.5 Tesla, while 3 Tesla MRI devices are expected to increase, and in the future even more powerful MRI devices, such as 6 Tesla MRI devices, can be expected. Thus, the frequency of the pulsed RF signal, or RF field, produced in a 1.5T MRI device is about 64 MHz, and about 128 MHz in a 3T MRI device. Now consider the pulsed RF signal from a wave perspective, i.e. as an RF wave propagating at a propagation speed. On its way to the implanted lead, the RF wave first passes through the boundary between the air and the body tissue. The RF wave undergoes a speed reduction from the speed in air v_0 to a speed in the human body v_1 due to the permittivity (ϵ) of the human tissue, where $v_1 = v_0 / \sqrt{\epsilon}$. The wavelength λ is also reduced by the same factor, i.e. $\lambda_1 = \lambda_0 / \sqrt{\epsilon}$. The permittivity is frequency dependent. However, at the frequency interval in question, the permittivity of the human tissue on average is in such an order that the resulting wave length in the human tissue comes close to the physical length of a typical medical implantable lead, e.g. in the order of half a meter. This causes a pacemaker lead to act as an antenna. The RF energy of the RF wave, or field, is picked up by the lead, and is partly transferred to the lead tip, causing heating of the tip.

Efforts have been made to try to solve the induced current and heating problems. For example, US 2009/0171421 discloses different ways to provide an MRI shield around the conductors of an implantable lead. The shield is obtained by providing a structure of, typically two, conductors separated and surrounded by an insulator, where the insulator acts as a dielectric part and forms a high impedance circuit in combination with the conductors. The high impedance is high to RF waves, which are thereby unable to cause the above-mentioned induced currents being large enough to cause the heating problem. Embodiments are for example disclosed where high capacitance segments are obtained by connecting the conductors by capacitors at intermediate locations. When there are more than two conductors it is disclosed that several high impedance circuits can be formed with different conductor pairs. It is not clear from the document how the capacitors are realized, but in case of discrete components this is a disadvantageous solution. In any case it is difficult to obtain segments with different capacitances in the structure.

SUMMARY OF THE INVENTION

It is an object of the invention to reduce the prior art problems described above related to an implantable medical lead when a person having such a lead implanted is subject to an MRI scanning.

The object is obtained with an implantable medical lead as defined in the appended claims.

Thus, according to an aspect of the invention, there is provided a medical implantable lead, comprising an elongate conductor enclosed by an elongate enclosing body, wherein the elongate enclosing body comprises an insulating material doped with particles of a conducting material, which particles are dispersed in the insulating material. The conducting material is chosen from a group of conducting materials which are able to provide percolation, wherein the enclosing material causes a frequency dependent loss of signal energy of signals propagating along the conductor, wherein a doping concentration of the conducting material is chosen such that the loss of energy of a utility signal is negligible, and the loss of energy of a radio frequency signal is significant within a frequency interval covering the frequency of an electro magnetic radio frequency field originating from a Magnetic Resonance Imaging apparatus.

By utility signal is meant a signal that is utilized for the purpose of a device connected to the lead, such as a signal fed through the conductor in order to be applied from a device at a proximal end of the lead to human tissue at a distal end of the lead, or from a sensor at a distal end of the lead to a device at a proximal end of the lead. Percolation is known as conduction between separate conductive particles dispersed in an insulating material, which occurs under particular circumstances, as will be further explained below in the description of embodiments. The present invention makes use of a phenomenon that occurs in a conducting material doped insulating material of a medical implantable lead, wherein the conducting material is of a kind that is able to cause percolation. The phenomenon is the frequency dependent loss, where the loss at utility signal frequencies is negligible, while the loss increases with frequency, reaches a maximum and then decreases again. However, at certain doping concentrations the loss is significant at least within a frequency interval that covers the radio frequency (RF) of an electro magnetic field originated from a Magnetic Resonance Imaging (MRI) apparatus.

The effect of this kind of enclosing body in the medical implantable lead is that the enclosing body acts as a low pass filter, filtering away the RF field in the axial direction along the length of the medical implantable lead. In other words, utility signals propagating along the conductor sees a high impedance in the insulating body, while the RF field sees a low impedance in the insulating body. This will be further explained below in the description of embodiments.

In accordance with an embodiment of the medical implantable lead of the present invention, the group of conducting materials comprises carbon black, carbon nanotubes (cnt), metal particles of nanodimensions, silica graphite, ferrite, and ionic salts, which all are able to provide the percolation phenomenon, when mixed into a non-conductive base material.

In accordance with an embodiment of the medical implantable lead the conducting material is carbon black. Carbon black has shown reliable properties and is easily mixable with the insulating material.

In accordance with an embodiment of the medical implantable lead the loss at the frequency interval, i.e. at RF frequencies used by MRI devices, is at least 10 dB/m. At such a loss the heating of the lead tip is below hazardous levels.

In accordance with an embodiment of the medical implantable lead at least a part of the conductor is coated with ethylene-tetrafluoroethylen (ETFE). Thereby the low frequency impedance is increased.

5 In accordance with an embodiment of the medical implantable lead the elongate conductor is an inner coil of a coaxial arrangement further comprising an outer coil, an intermediate tube constituted by the elongate enclosing body and arranged between the outer coil and the inner coil, and an outer tube constituted by a further elongate enclosing body and enclosing the outer coil.

10 In accordance with an embodiment of the medical implantable lead the insulating material is chosen from a group of insulating materials comprising silicone rubber, optim, polyurethane elastomers, and electrically insulating biocompatible elastomeric compounds.

In accordance with an embodiment of the medical implantable lead the frequency of the utility signal is below 10 kHz, and the frequency interval includes at
15 least 64 MHz and 128 MHz.

These and other aspects, features, and advantages of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

20

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in more detail and with reference to the appended drawings in which:

25 Fig. 1 is a schematic side view of a medical implantable device;

Fig. 2 is a schematic longitudinal sectional view of a portion of an embodiment of a medical implantable lead according to the present invention;

Fig. 3 a schematic longitudinal sectional view of a portion of an embodiment of a medical implantable lead according to the present invention;

30 Fig. 4 a schematic longitudinal sectional view of a portion of another embodiment of a medical implantable lead according to the present invention;

Fig. 5 is a schematic longitudinal sectional view of a portion of another embodiment of a medical implantable lead according to the present invention;

Fig. 6 is a schematic partly cut-away view of a portion of another embodiment of a medical implantable lead according to the present invention;

Fig. 7 is a schematic partly cut-away view of a portion of another embodiment of a medical implantable lead according to the present invention;

5 Fig. 8 is a diagram of loss versus signal frequency for a first doping concentration; and

Fig. 9 is a diagram of loss versus signal frequency for a second doping concentration.

10 DESCRIPTION OF PREFERRED EMBODIMENTS

Percolation is a phenomenon where conductive particles dispersed in an insulating material, or at least some insulating materials, the conductive particles theoretically being homogeneously dispersed and being in non-physical contact with each other, at a certain doping concentration are close enough to create a 3-
15 dimensional network which is actually able to conduct electricity. This conduction is assumed to occur by tunneling of electrons when the distance between the particles is less than a few nanometers, and/or the conduction occurs when capacitances are formed inbetween the particles. In practice the particles are not completely homogeneously dispersed but gathered in agglomerates, where the
20 tunneling/capacitance forming occurs between agglomerates. When the doping concentration is increased a sharp increase in conductivity is observed at a particular doping concentration. The doping concentration where this percolation occurs is called percolation threshold. In a report "Dielectric Relaxation of Ensaco®350G Reinforced Microcellular EPDM Vulcanizates" by S.P. Mahapatra et.
25 al., Polymer Composites, 2007, pp. 657-666, it is mentioned that a theoretical value of the percolation threshold for randomly-dispersed hard and spherical particles has been determined to be about 16 % by volume. In practice the percolation threshold depends on the type of insulating material and the characteristics of the conductive particles, such as nitrogen surface area, surface activity, particle size, morphology,
30 how the materials are mixed, etc. in practice, the percolation threshold is typically above 16 % by volume.

As explained above, the present invention makes use of the fact that when constructing a medical implantable lead having at least one conductor enclosed by

an enclosing body comprising such doped insulating material, the enclosing body causes a frequency dependent loss of a signal propagating along the conductor. The loss is dependent on the doping concentration, and increases by frequency up to a maximum loss and then decreases again at even higher frequencies. This is shown in Figs. 8 and 9, where a silicone rubber was chosen as the insulating material and carbon black was chosen as the conductive particles, and dispersed in the silicone rubber. The length of the lead was about half a meter. The enclosing body was grounded in order to simulate contact with body tissue. Due to difficulties in setting up the test in an MRI apparatus, the induced current was simulated by a test signal which was introduced into the conductor at a proximal end of the lead and the output of the signal was measured at the distal end of the lead. In Fig. 8 the doping concentration was 9 % by weight of carbon black, and in Fig. 9 the doping concentration was 14 % by weight. It can be seen that in both cases there was a significant loss at typical MRI frequencies, i.e. 64 MHz and 128 MHz, while the loss below some ten kHz it was very low, and for the purposes of the invention it was negligible. For instance, at a doping concentration of 14 % by weight, the loss is approximately 36 dB at 64 MHz, and the loss is about the same at 128 MHz. In an ideal case an even more distinct increase of the loss would occur. The somewhat smeared effect is probably due to an agglomerated structure of the carbon black particles in the silicone rubber. Regarding a necessary dampening of the RF energy by means of the lossy enclosing body this dampening is in addition to a basic dampening of the lead as such. However, as mentioned above, a dampening in the order of 10 dB/m provided by the lossy enclosing body is regarded as necessary to lower the heating of the lead tip to an acceptable level. As shown above, according to the invention dampening far beyond that figure is achievable.

As regards the RF frequency interval where the loss is significant, in some applications a significant loss will be required already at about 0.5 MHz, while in other applications a significant loss will be required at frequencies above 128 MHz, such as for example at 256 MHz for a 6T MRI apparatus, which probably will be employed in the future. By making appropriate choices of insulating material, conductive material and doping concentration it will be possible to tailor limits of the frequency interval as desired, in accordance with the present invention.

From the experiments described herein, it can be seen that the frequency dependent loss occurs already at doping concentrations below the percolation threshold. However, while the loss increases dramatically with the doping concentration at the desired RF frequencies, it also increases at utility frequencies.

5 Thus, there is a maximum doping concentration that is useful in order not to dampen the utility signals to a critical extent. This effect is addressed in some embodiments as will be described below.

The basic electrical property of the enclosing body that changes radically at percolation, and that is tightly related to the impedance and conductivity variations
10 discussed above, is the permittivity ϵ . The permittivity is frequency dependent and is expressed by complex number notation, as $\epsilon = \epsilon' - j\epsilon''$. The real part ϵ' is named dielectric constant and is representative for how much energy from an external field is stored in the material. The imaginary part ϵ'' is named loss factor, and is representative for the loss energy dissipative mechanisms in the material. For
15 nonconductive materials, such as the silicone rubber and other appropriate lead insulators, the real part and the imaginary part of the permittivity slightly decrease with increasing frequency. Furthermore, the dependence of loss factor upon frequency is usually described by a sum of two terms; $\sigma_0/2\pi f$, accounting for conductive effects, and ϵ''_R , accounting for relaxation effects, which gives:

20

$$\epsilon''(f) = \sigma_0/2\pi f + \epsilon''_R(f)$$

It is anticipated that the rapid increase in loss at higher frequencies in the experiments presented above, is directly related to a corresponding increase in the
25 loss factor ϵ'' .

It should be noted that in above-mentioned US 2009/0174121, in paragraph [0083] referring to fig. 5A, there is disclosed a lead structure embodiment that comprises "...lead systems formed with high impedance segments of two or more insulated conductors 20c with any single conductor and/or a composite conductor
30 structure having a polymeric layer 13 over them. The leads may be further shielded by a polymeric dielectric material with metal or conductive particles 13c dispersed therein to shield/deflect external RF". There is no further explanation of properties of the polymeric dielectric material with conductive particles. In particular there is no

referral to the percolation phenomenon, which provides the non-linear frequency response utilized in accordance with the present invention, and the lead structure embodiment is based on the basic structure with the conductors being connected by capacitors at intermediate locations. In contrast to the blocking effect that is stated
5 to be obtained by means of the high impedance structure disclosed in US 2009/0174121, the enclosing body/bodies according to the present invention is a low impedance component at high frequencies, i.e. at MRI RF wave frequencies. In other words, at those frequencies the enclosing body (bodies) behaves like a lossy capacitor to the RF wave, draining away the RF energy axially along the length of
10 the lead. This means that, rather than concentrating the energy to the lead tip due to induced currents in the conductor, the present structure distributes the RF energy over a large area, causing a negligible heating of the lead. At the same time the utility signals sent through the conductor are in such a frequency range that they experience the enclosing body as a high impedance keeping the signals within the
15 conductor.

Referring to Fig. 1, a typical medical implantable device 101 comprises a medical implantable lead 103 and an electric unit, such as for instance a pacemaker, 105. The medical implantable lead 103 has a lead tip 107, which is to be connected to body tissue and which is connected to at least one conductor of the
20 medical implantable lead 103, and at least one lead ring 109, which is connected to at least one further conductor of the medical implantable lead 103.

Below the term "lead" will be used as a synonym to the expression "medical implantable lead".

A first embodiment of a medical implantable lead in accordance with the
25 present invention, comprises an elongate coaxial arrangement 201, a portion of which is schematically shown in Fig. 2. The coaxial arrangement 201 extends between a proximal end 111 of the medical implantable lead 103, where it is connected with the electrical unit 105, using the coaxial arrangement to send utility signals to and/or receive utility signals from a desired part of the body, and a distal
30 end 113 of the lead 103, where it is connected with the lead tip 107, and the lead ring 109, which interact with the body tissue. Since this overall structure of a typical medical implantable lead is well known to the person skilled in the art, no further explanation thereof will be set forth here. The coaxial arrangement 201 comprises

two conductors and two insulating bodies. More particularly, the coaxial arrangement 201 comprises a coiled elongated inner conductor 203, a coiled elongated outer conductor 205, an intermediate first elongated enclosing tube 207, arranged between the outer conductor 205 and the inner conductor 203, and a second elongate enclosing tube 209 enclosing the outer conductor 205 and forming an outer tube of the coaxial arrangement 201. Each one of the conductors 203, 205 is a 5-filar conductor, i.e. it is constituted by five separate filars, or subconductors extending helically in parallel. Comparing with Fig. 1, at the distal end of the lead 103 the inner conductor 203 is connected with the electrode tip 107, and the outer conductor 205 is connected with the electrode ring 109.

Referring to the enclosing bodies, i.e. the enclosing tubes, 207, 209, silicone rubber is chosen as insulating material and the silicone rubber is doped with a very fine conductive powder of carbon black. The doping concentration of carbon black preferably is about 9-14 % by weight.

While obtaining the advantageous loss effect by doping the insulation material with conductive particles like carbon black, the impedance between the lead tip 107 and the lead ring 109 decreases significantly with increasing doping concentration at all signal frequencies. If the impedance decreases below a critical level, it is possible to overcome this problem by coating the conductors, or at least portions thereof, such as the tip 107, the ring 109, both the tip and the ring, or the whole of one or more conductors with an additional insulating layer. For example, ETFE, ethylene-tetrafluoroethylen, is an appropriate material for such an insulating layer. This is illustrated in Fig. 3, where a coaxial arrangement 301 similar to that of Fig. 2 is shown. In this second embodiment at least an inner conductor 303 is coated with a layer 305 of ETFE. It should be noted that in fact the inner conductor 303 is constituted by five separate filars 303a, or subconductors, which have been coiled extending helically side by side. At utility signal frequencies a thin oxide layer on the filars keep the signals within the filars, but when the doping concentration of the enclosing tube increases an energy leakage occurs to the enclosing tube. The leakage is stopped by the ETFE layer 305. For MRI RF field frequencies, such as 64 MHz or 128 MHz, the capacitance between the filars is an important factor. The energy is coupled straight across the filars and propagates more or less like in a conductive tube. When the doping concentration increases the leakage to the

enclosing tube 307 increases abruptly, which is advantageous. The application of the ETFE layer 305 causes a substantial capacitance decrease between the filars leading to the RF energy propagating along the filars. Thereby, the coiled conductor 303 acts as an inductance which counteracts the induction of the RF energy into the conductor 303. Still the basic loss of RF energy in the enclosing body remains, since in the coaxial structure the RF energy propagates mainly between the conductors and crosses both the enclosing body and the ETFE layer. In a non-coaxial arrangement the RF energy will propagate mainly in a surface region of the conductor due to the skin effect. Other materials than ETFE can be used for the coating. Uncoated and coated conductors can be combined in a lead.

According to a third embodiment of the medical implantable lead, a portion of which is shown in Fig. 4, the lead 401 has a coaxial structure similar to that of the lead shown in Fig. 2, i.e. an inner coiled conductor 403, an intermediate enclosing tube 405, an outer coiled conductor 407, and an outer enclosing tube 409. The enclosing tubes 405, 409 have been doped with conductive particles. In addition the intermediate enclosing tube 405 comprises at least one segment 411, which has been doped to a higher doping concentration than the rest of the intermediate enclosing tube 405. Similarly, the outer enclosing tube 409 comprises at least one segment 413, which has been doped to a higher doping concentration than the rest of the outer enclosing tube 413. The segments 411, 413 of the intermediate and outer enclosing tubes 405, 409 are coaxially arranged relative to each other. The segments 411, 413 of higher doping concentration provides a shunting of the RF signal energy from the conductors 403, 407 to the surrounding body tissue, when the lead 401 has been mounted in a person who is subjected to MRI scanning. Alternatively, several such additionally doped segments 411, 413 are provided along the lead 401.

According to a fourth embodiment of the medical implantable lead, a portion of which is shown in Fig. 5, the lead 501 is constituted by a single elongated conductor 503 and an elongated enclosing body 505, which encloses the conductor 503. The enclosing body 505 is filled with conductive particles dispersed therein as described above. The conductor 503 is coiled.

Referring to Fig. 6, according to a fifth embodiment of the medical implantable lead 601 it comprises two parallel straight conductors 603, 605,

embedded in an insulating body 607 doped with conductive particles. The number of parallel conductors can be higher, and coiled and straight conductors can be combined in one and the same lead.

Referring to Fig. 7, a distal portion of an embodiment of the medical
5 implantable lead is shown in a more detailed view. The lead 701 has a coaxial arrangement of an inner elongate conductor 703, which is coiled, an intermediate elongate enclosing body 705, an outer elongate conductor 707, an outer elongate enclosing body 709, an electrode tip 711, connected with the inner conductor 703, and an electrode ring 713, connected with the outer conductor 707. The electrode
10 tip 711 is shown in its retracted position.

In addition to insulating materials mentioned above in the summary of the invention, further materials of interest are for instance polytetrafluoroethylene and similar derivatives of teflon[®], polyisobutylene and other aliphatic derivatives, in various combinations. Furthermore, thermoplastic polyurethane elastomer based materials
15 can be compounds comprised of a mix of hard and soft portions of different materials.

CLAIMS

1. A medical implantable lead, comprising an elongate conductor enclosed by an elongate enclosing body, wherein the elongate enclosing body comprises an insulating material doped with particles of a conducting material, which particles are dispersed in the insulating material, characterized in that the conducting material is chosen from a group of conducting materials which are able to provide percolation, wherein the enclosing body causes a frequency dependent loss of signal energy of signals propagating along the conductor, wherein a doping concentration of the conducting material is chosen such that the loss of energy of a utility signal is negligible, and such that the loss of energy of a radio frequency signal is significant within a frequency interval covering the frequency of an electro magnetic radio frequency field originating from a Magnetic Resonance Imaging apparatus.
2. A medical implantable lead according to claim 1, wherein the group of conducting materials comprises carbon black, graphite, ferrite, ionic salts, carbon nanotubes, metal particles of nanodimensions, and silica.
3. A medical implantable lead according to claim 2, wherein the conducting material is carbon black.
4. A medical implantable lead according to any one of claims 1 to 3, wherein said significant loss is more than 10 dB/m.
5. A medical implantable lead according to any one of claims 1 to 4, wherein at least a part of the conductor is coated with ethylene-tetrafluoroethylen.
6. A medical implantable lead according to any one of claims 1 to 5, wherein said elongate conductor is an inner coil of a coaxial arrangement further comprising an outer coil, an intermediate tube constituted by the elongate enclosing body and arranged between the outer coil and the inner coil, and an outer tube constituted by a further elongate enclosing body and enclosing the outer coil.
7. A medical implantable lead according to any one of claims 1 to 6, wherein the medical implantable lead is one of a pacemaker lead, an implantable cardioverter defibrillator lead, an implantable pulse generator lead, and a neurostimulation lead.
8. A medical implantable lead according to any one of claims 1 to 7, wherein the insulating material is chosen from a group of insulating materials comprising

silicone rubbers, optim, polyurethane elastomers, and electrically insulating biocompatible elastomeric compounds.

- 5 9. A medical implantable lead according to any one of claims 1 to 8, wherein the frequency of the utility signal is below 10 kHz, and wherein said frequency interval includes at least 64 MHz and 128 MHz.

- 10 10. A medical implantable lead according to any one of claims 1 to 9, wherein the lead has a coaxial structure comprising an inner elongate conductor, an intermediate elongate enclosing tube, an outer elongate conductor, and an outer elongate enclosing tube, wherein the enclosing tubes are doped with conductive particles, and wherein the intermediate enclosing tube has at least one segment which has been doped to a higher doping concentration than the rest of the intermediate enclosing tube, wherein the outer enclosing tube has at least one segment which has been doped to a higher doping concentration than the rest of the outer enclosing tube, and wherein the segments of the intermediate and outer enclosing tubes are arranged coaxially of each other.
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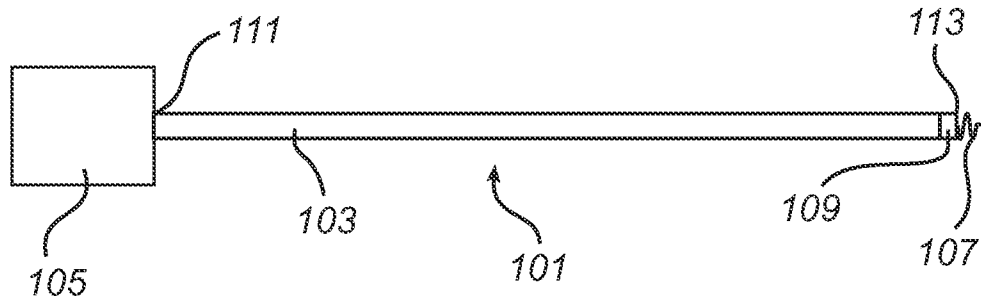


Fig. 1

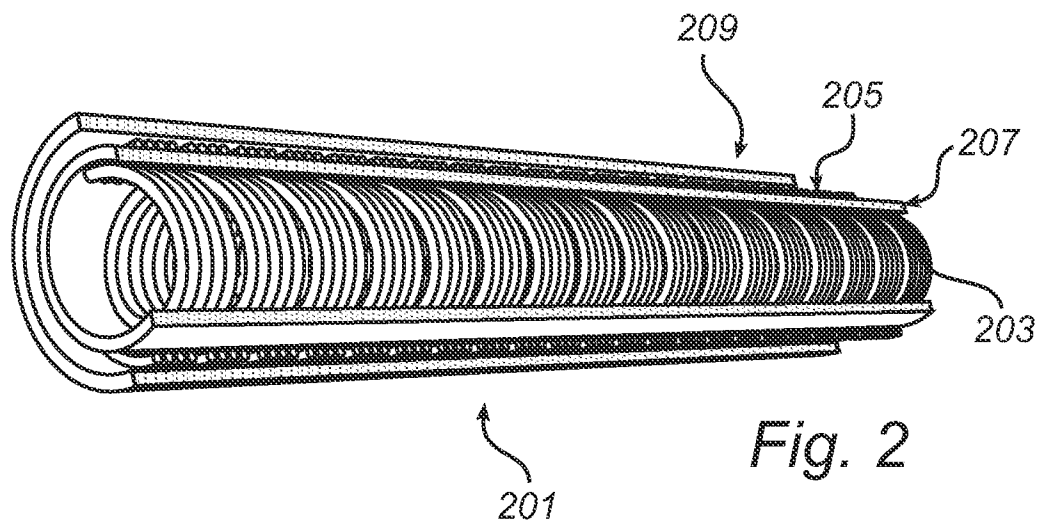


Fig. 2

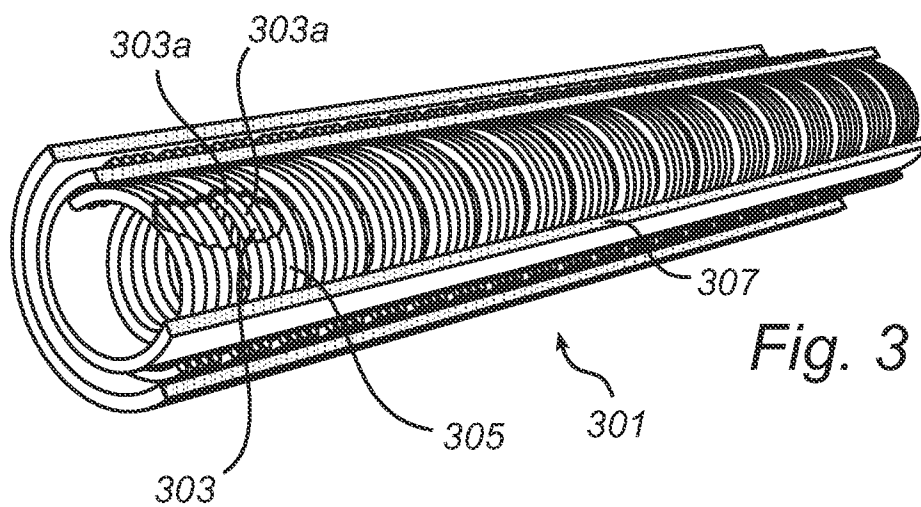
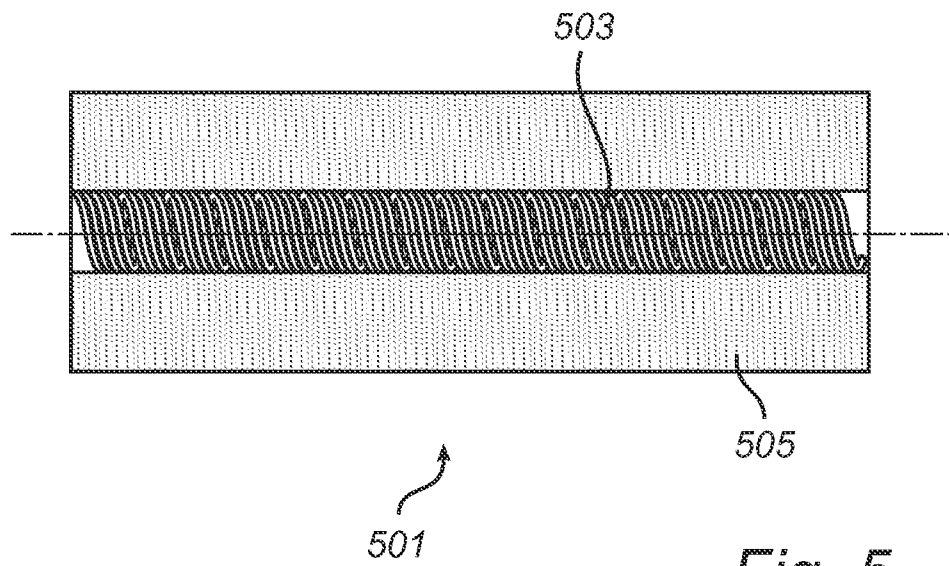
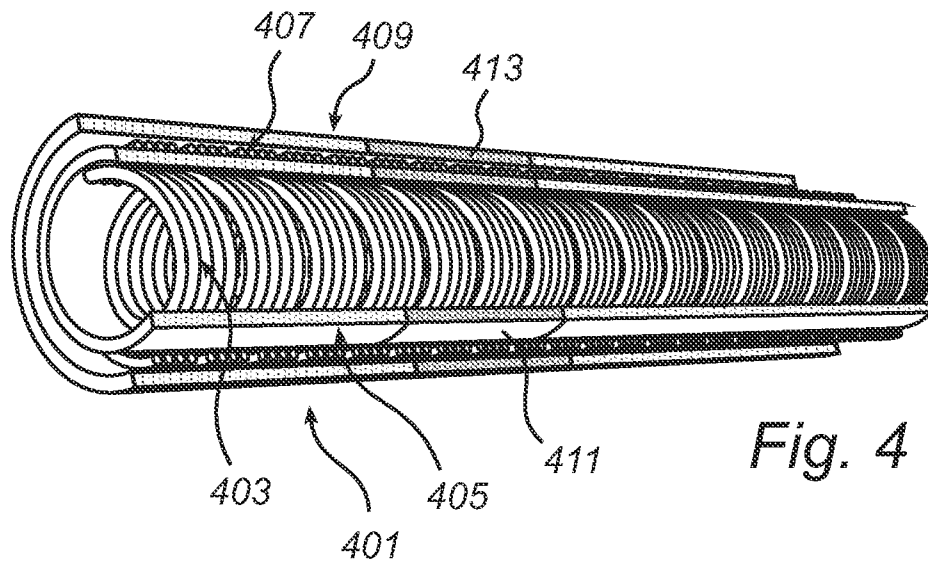
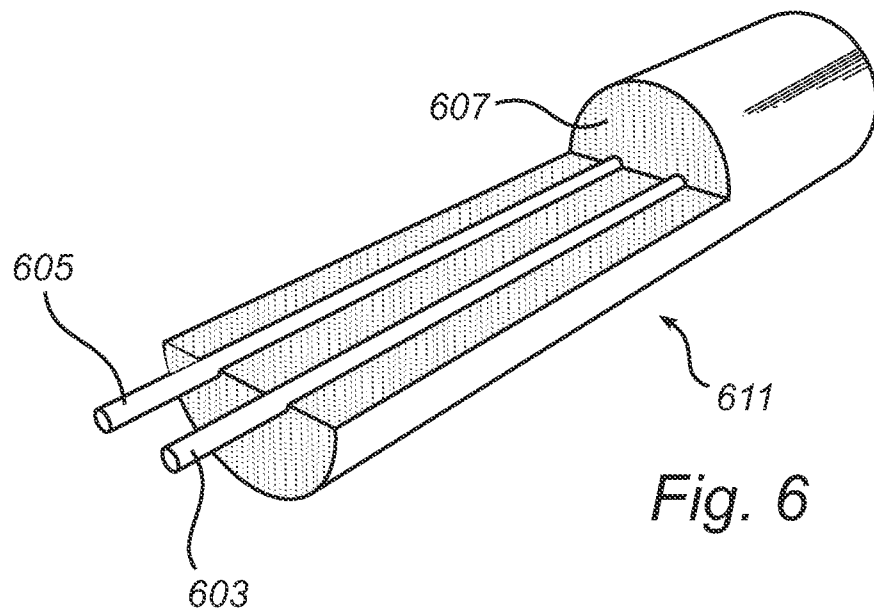


Fig. 3

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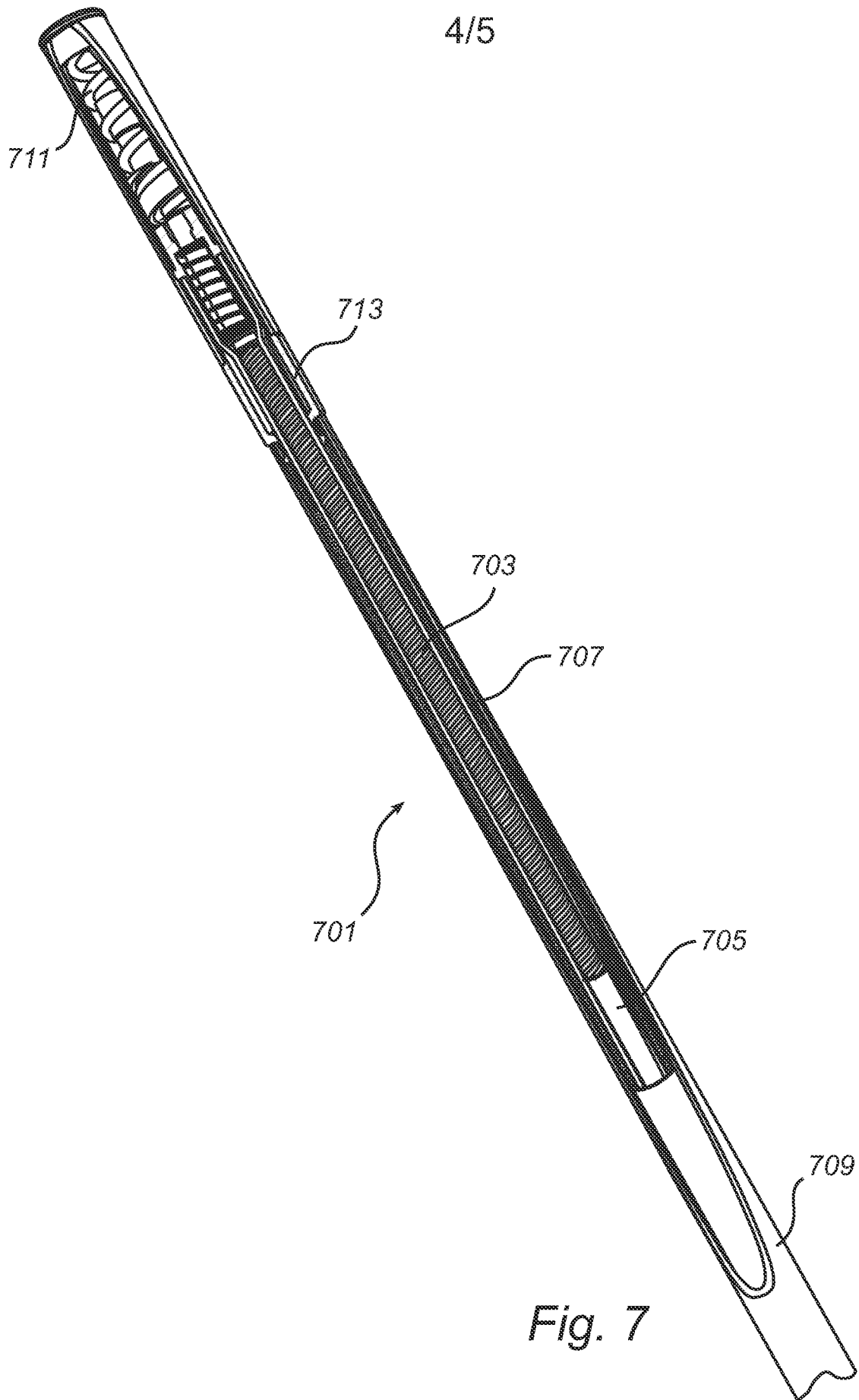
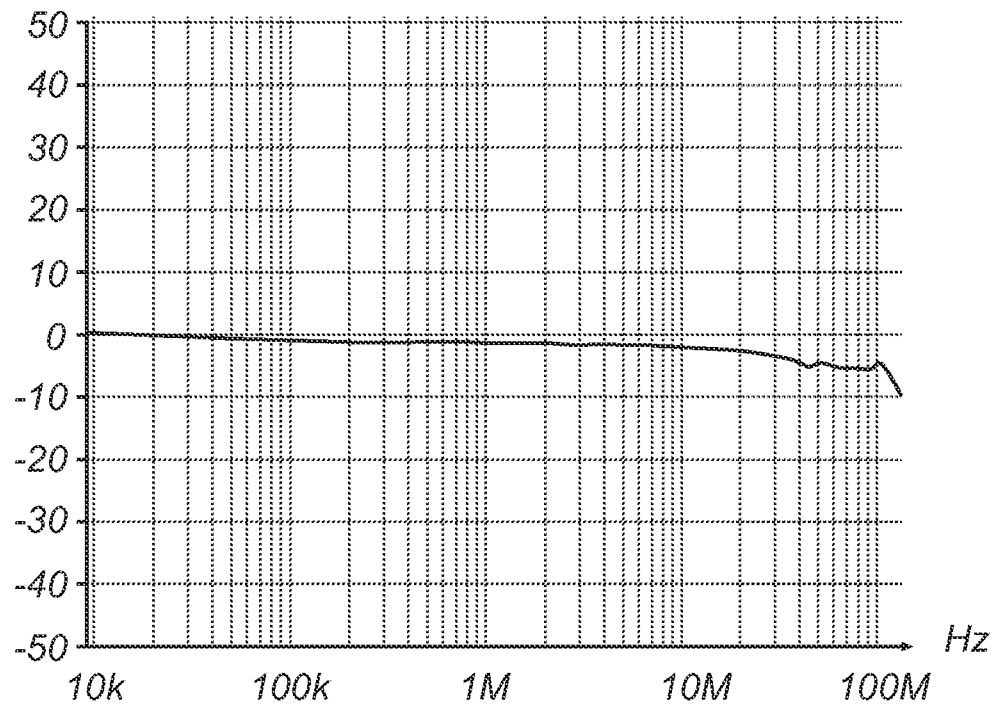
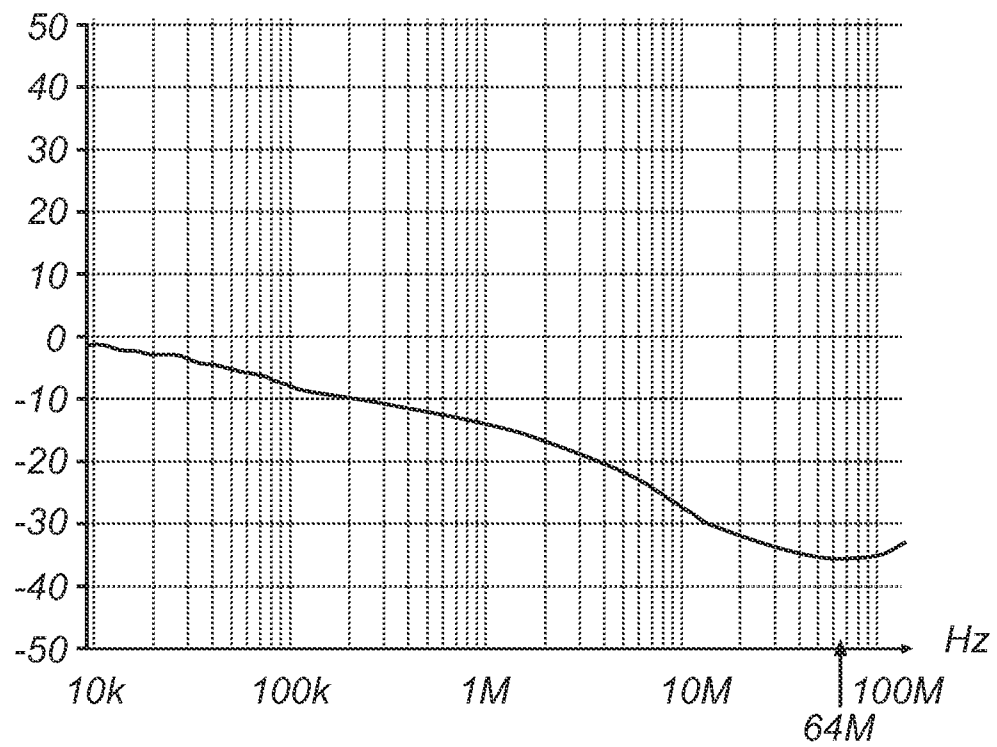


Fig. 7

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*Fig. 8**Fig. 9*

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE2010/050364

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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)

IPC: A61N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI DATA, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 20050222657 A1 (WAHLSTRAND ET AL), 6 October 2005 (06.10.2005), figures 20-21, abstract, claims 1,7-9,11,15,19-23; paragraphs (0012),(0037),(0048),(0057)-(0063) --	1-10
X	DE 102007022333 A1 (BIOTRONIK CRM PATENT AG), 13 November 2008 (13.11.2008), figures 5-6, claims 1,13, abstract, paragraphs (0030)-(0033) --	1-10
A	J. Markarian. "Increased demands in electronics drive additive developments in conductivity". PLASTICS ADDITIVES AND COMPOUNDING, vol 7, Nr 30 PG 26-30. 2005, ICPs, carbon nanotubes; abstract --	1-10

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

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Date of the actual completion of the international search

30 November 2010

Date of mailing of the international search report

09-12-2010

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE2010/050364

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	L. J. Adriaanse, et al. "High-Dilution Carbon-Black/Polymer Composites: Hierarchical Percolating Network Derived from Hz to THz ac Conductivity", Physical Review Letters, vol. 78, No. 9, March 1997, whole document --	1-10
A	US 20090149920 A1 (LI ET AL), 11 June 2009 (11.06.2009), abstract, paragraphs (0038),(0050), (0054) --	1-10
A	US 20080154346 A1 (SMITH ET AL), 26 June 2008 (26.06.2008), abstract, paragraphs (0182)-(0183) --	1-10
A	US 20030144720 A1 (VILLASECA ET AL), 31 July 2003 (31.07.2003), figure 4, abstract, paragraphs (0006),(0030) --	1-10
A	US 20060009819 A1 (PRZYBYSZEWSKI), 12 January 2006 (12.01.2006), figure 1, abstract, paragraph (0012) --	1-10
A	US 20080119917 A1 (GEISTERT), 22 May 2008 (22.05.2008), abstract -- -----	1-10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2010/050364

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A61N 1/16 (2006.01)

A61N 1/05 (2006.01)

A61N 1/08 (2006.01)

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International application No. PCT/SE2010/050364
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US	20030144720	A1	31/07/2003	NONE

US	20060009819	A1	12/01/2006	NONE

US	20080119917	A1	22/05/2008	NONE
