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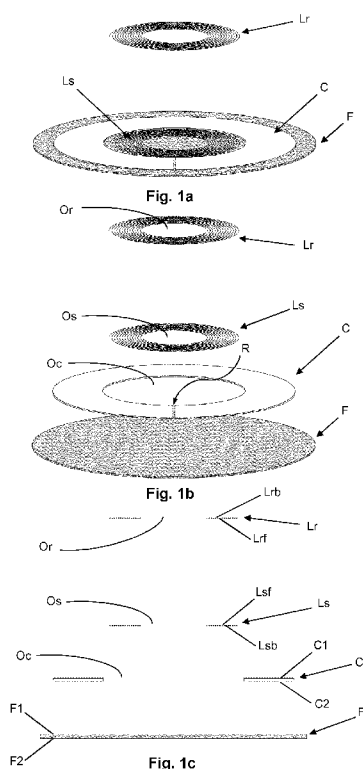
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(54) Title: A MAGNETIC DEVICE AND A MAGNETIC SYSTEM TO ENHANCE WIRELESS POWER TRANSMISSION, AND USES OF THE DEVICE



(57) Abstract: The magnetic device comprises a first part (C), made of a material which is an electrical conductor or at least partially diamagnetic, having a through-hole (Oc) and arranged over the back surface (Lsb, Lrb) of the emitter or receiver coil (Ls, Lr) with its through-hole (Oc) placed, at least in part, over the coil through-hole (Os, Or), or aligned with the coil (Ls, Lr). The magnetic system comprises a source and a receiver of a magnetic field, and one or two magnetic devices according to the invention. The uses of the magnetic device of the present invention are for, respectively, a high frequency range wireless power transmission and a low frequency range wireless power transmission.



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**A magnetic device and a magnetic system to enhance wireless power
transmission, and uses of the device**

Field of the Invention

5 The present invention generally relates, in a first aspect, to a magnetic device to enhance wireless power transmission, through magnetic coupling, between a source and a receiver of a magnetic field, having respective coils, and more particularly to a magnetic device comprising at least a first part made of a material which is an electrical conductor or mainly diamagnetic arranged or to be arranged over a back surface of the
10 coil of the source or of the receiver.

 Second and third aspects of the invention relate to the uses of the device of the first aspect for, respectively, a high frequency range wireless power transmission and a low frequency range wireless power transmission.

 A fourth aspect of the invention relates to a magnetic system to enhance wireless
15 power transmission, comprising a source and a receiver of a magnetic field, and one or two devices according to the first aspect of the invention.

Background of the Invention

 Wireless power transfer (WPT) is in general achieved using different strategies.
20 One of the most relevant approaches is based on resonant/non-resonant magnetic induction between distant coils. In this case one coil (emitter or source) is connected to an AC power generator so that it creates an AC magnetic field. This field induces a current to a second coil (receiver), which then can be used to power a device or can be stored.

25 Generally, the distance achieved for wireless power transferring at least part of the emitted power is very small. It is known that in free space at a distance of just three times the diameter of the coil of the source almost no power is received.

 There are very few proposals focused on enhancing the wireless power transmission, i.e. in increasing the power that can be delivered at a certain distance
30 and/or increasing the distance at which certain power can be delivered.

 One of said proposals is disclosed at "Magnetic Metamaterial Superlens for Increased Range Wireless Power Transfer if the receiver is placed" (2), Guy Lipworth et al, Scientific Reports, Nature Publishing Group, Jan 10, 2014. The proposed metamaterial superlens is formed by a slab of several cells of three mutually orthogonal
35 resonators and the enhancements on power transmission have been observed to obtain

those transfer distances of 4–12 times greater than the diameter of both transmitter and receiver coils.

Said metamaterial superlens constitutes a very complex device for WPT enhancement, both structurally and regarding the construction and needing of such a specific metamaterial.

Increasing the magnetic coupling between distant coils is a well-recognized way to improve the WPT efficiency. To increase this coupling metamaterials with exotic properties have been proposed and experimentally demonstrated [1].

The concept behind most of these metamaterials is the 'perfect lens' (or 'superlens'), which was anticipated by Veselago [2] and rigorously proposed by Pendry [3]. This was based on a slab of material having simultaneously negative permittivity and permeability, i.e. a negative refraction index. Pendry also showed that in the deep-subwavelength limit, electric and magnetic fields decouple, and only one parameter of ϵ and μ needs to be negative to make a 'superlens'. Depending on whether the near field is dominated by the electric field or the magnetic field, only $\epsilon < 0$ or $\mu < 0$ is required.

The idea of using a 'superlens' to enhance the wireless transmission of energy was proposed in 2010 [4] by a Mitsubishi Electric Research Laboratories (MERL) group. In 2011, a more rigorous study was performed by the Smith's group [5] based on an analytical model of the coupling between two coils and a homogeneous metamaterial slab.

In 2011 experiments on WPT with a metamaterial slab were done [6]. There, the power was transferred via the coupling of near-field magnetic field. Thus, a 'single-negative' metamaterial with $\mu < 0$ and $\epsilon > 0$, or a magnetic metamaterial was designed. The unit cells of the fabricated metamaterial slab where double-side square spirals and it was able to improve the WPT efficiency from 17% to 47% and transferring up to 40W.

In 2012, Smith's group published a work [7] in which finite-element based simulations were used to analyse the mutual coupling between finite-diameter coils situated on either side of a finite-sized planar lens.

Recently in 2013, a different strategy to increase the WPT has been explored by the MERL group [8]. They studied the use of artificial magnetic conductors placed behind the coils to increase the coupling between them so that no material needs to be placed between them. Although no natural magnetic conductors exist, authors claim they could be built with resonant metamaterials.

A different proposal to enhance WPT (not using metamaterials) is disclosed in US2013264864A1, which relates to a wireless power transmission system which includes a first inductor and a second inductor constituting respectively an emitter and a

receiver of the WPT, or vice versa, and a magnetic body member made of a ferromagnetic material, that is arranged on one side of one of the first or second inductors, particularly over the side facing the other inductor, i.e. between the emitter and the receiver.

- 5 Said proposal is limited to the case when one of the inductors is smaller in size than the hole of the other inductor and, among others, has the drawback that it does not take profit of the magnetic field existing in the back side of the inductors and that the magnetic body invades the free space existing between the facing inductors, in other words it constitutes a protrusion which by itself reduces the distance between the emitter
10 and the receiver.

References:

- [1] B. Wang, W. Yerazunis, K. H. Teo, Proceedings of the IEEE, 101, 1359 (2013).
15 [2] V. G. Veselago, Sov. Phys. Usp. 10, 509 (1962).
 [3] J. B. Pendry, Phys. Rev. Lett. 85, 3966 (2000).
 [4] B.Wang, T. Nishino, and K. H. Teo, Proc. IEEE Int. Conf. Wireless Inf. Technol. Syst., Honolulu, HI, USA, Aug. 28Sep. 3, (2010).
 [5] Y. Urzhumov and D. R. Smith, Phys. Rev. B, 83, 205114 (2011).
20 [6] B. Wang, K. H. Teo, T. Nishino, W. Yerazunis, J. Barnwell, and J. Zhang, Appl. Phys. Lett., 98, 254101 (2011).
 [7] D. Huang, Y. Urzhumov, D. R. Smith, K. H. Teo, and J. Zhang, J. Appl. Phys., 111, 64902 (2012).
 [8] J. Wu, B. Wang, W. S. Yerazunis, K. H. Teo Proc. 2013 IEEE Wireless Power
25 Transfer (WPT), 155 (2013).
 [9] G. Lipworth, J. Ensworth, K. Seetharam, D. Huang, J. S. Lee, P. Schmalenberg, T. Nomura, M. S. Reynolds, D. R. Smith, and Y. Urzhumov, Scientific Reports 4, 3642 (2014).
 [10] Irwin, J. D., and Nelms, R. M. Basic engineering circuit analysis. John Wiley & Sons
30 (2007).

Description of the Invention

- It is an object of the present invention to offer an alternative to the prior state of the art, with the purpose of providing a device to enhance WPT which overcomes the
35 drawbacks of the known devices, which is simpler and does not invades the free space between the emitter and the receiver.

To that end, the present invention relates, in a first aspect, to a magnetic device to enhance wireless power transmission, through magnetic coupling, between a source of a magnetic field and a receiver of a magnetic field, directing the magnetic field generated from the source to the region where the receiver is located, said source and
5 said receiver of a magnetic field having respective coils facing each other by respective front surfaces and having respective back surfaces, where each pair of said front and back surfaces are placed in respective opposite planes which are orthogonal to the magnetic axis of the coil, each coil also having a through-hole extending between the front and the back surfaces, wherein the magnetic device is intended to be arranged
10 over one of said coils.

Contrary to the known devices, the device of the first aspect of the present invention comprises a first part, made of a material which is an electrical conductor or at least partially diamagnetic with diamagnetism as its main contribution to magnetism, said first part being or having a wall with first and second outer surfaces delimiting its
15 thickness, said wall having a through-hole traversing the thickness thereof, at least a portion of said first outer surface surrounding said wall through hole being flat and configured and intended to be arranged over said coil back surface with said wall through-hole placed, at least in part, over the coil through-hole, or to be arranged substantially aligned with one of said front and back surfaces of the coil or with a parallel
20 plane sandwiched between the coil front and back surfaces such that the through-hole of the first part surrounds the coil, wherein said first part has at least one slit extending from the through-hole to an outer perimeter edge of the first part.

For some embodiments, the device of the first aspect of the present invention further comprises a second part comprising at least one ferromagnetic element being or
25 having a wall with first and second outer surfaces delimiting its thickness, wherein:

- at least a portion of said first outer surface is flat and configured and intended to be arranged over said coil back surface covering the coil through-hole, at least in part; or
- said at least one ferromagnetic element is one of several ferromagnetic
30 elements being or having respective walls configured and intended to be arranged over the coil back surface in a transversal manner, such that said walls don't remain parallel to the coil back surface, with at least part of an upper edge of said walls being placed over at least a region occupied by said coil through-hole.

35 For those embodiments for which the device of the first aspect of the invention comprises both of said first and second parts, and the first part is placed over the coil

back surface, the second part is therefore placed over the first part, i.e. over the coil back surface, as stated above, but with the first part in between.

The device of the first aspect of the invention rearranges the magnetic energy in space, leading to an increase of the WPT neither modifying the distance between the emitting and receiving coils nor introducing any material between them, i.e. without
5 modifying the effective distance of free space between emitter and receiver.

Two typical frequency ranges are used, and are being standardized.

Said at least one ferromagnetic element is, preferably, made of a soft ferromagnetic material, with a large relative magnetic permeability, greater than 10, and
10 a low electric conductivity (smaller than $2 \cdot 10^6$ S/m), to minimize losses due to eddy currents and to maximize the skin depth associated to the AC magnetic field created by the coil. One of the most appropriate materials are ferrite sheets.

Although the device of the first aspect of the invention is fabricated, for an embodiment, without including any coil, such that it can be arranged on any coil of a
15 WPT system, for another embodiment the device further comprises said coil of the source or of the receiver of a magnetic field, such as a planar coil, wherein the flat portion of the first outer surface of the wall of the first part is arranged over the coil back surface with the wall through-hole placed over the coil through-hole or arranged substantially aligned with one of the front and back surfaces of the coil or with a parallel
20 plane sandwiched between the coil front and back surfaces such that the through-hole of the first part surrounds the coil.

For another embodiment, the flat portion of the first outer surface of the wall of the at least one ferromagnetic element of the second part is arranged over the coil back surface covering the coil through-hole or the walls of the several ferromagnetic elements
25 are arranged over the coil back surface in a transversal manner, such that the walls don't remain parallel to the coil back surface, with at least part of an upper edge of the walls being placed over at least a region occupied by the coil through-hole.

For an embodiment, the first part comprises two or more of said slits extending from the through-hole to different parts of the outer perimeter edge of the first part, such
30 that different portions of the first part are defined which are electrically isolated with respect to each other, and, optionally, also a support made of an electrically isolating material, to which said different portions of the first part are attached.

Said slit or slits is/are open to air or filled with an electrically isolating material.

According to a preferred embodiment, at least the flat portion of the first outer
35 surface of the wall of the first part is arranged or to be arranged adjacent to said coil back surface or in contact therewith.

The size of the through-hole of the first part is substantially equal, in size, or larger than the size of the through-hole of the coil, although if smaller a non-optimum but acceptable operation can also be achieved.

5 Preferably the through-hole of the first part and the through-hole of the coil are coaxial, or substantially coaxial, although a small shift between the axes of said through-holes does not avoid that a non-optimum but acceptable operation can be achieved

10 Preferably, at least one of the first and second surfaces of the walls of the several ferromagnetic elements, when arranged over the coil back surface, remain perpendicular thereto, although tilted walls are also encompassed for another embodiment of the magnetic device of the first aspect of the invention.

For a preferred embodiment, the first and second outer surfaces of the walls of said several ferromagnetic elements of the second part are flat, said walls being arranged adjacent and parallel to each other, said ferromagnetic elements constituting, for example, ferromagnetic sheets.

15 For another embodiment, the walls of said several ferromagnetic elements of the second part are cylindrical walls arranged concentrically to each other or, for still another embodiment, have respective hollow frustrum shapes, and each of them is at least partially introduced, by its smaller base, into the hollow inner space of an adjacent hollow frustrum-shaped wall, concentrically to each other.

20 Other shapes and arrangements for the walls of the several ferromagnetic elements of the second part are also possible, for other embodiments.

For an embodiment, the above mentioned at least one ferromagnetic element of the second part is only one ferromagnetic element, such as a ferromagnetic sheet, whose role is to create an "image" coil which adds to the field of the real one and
25 increases the transmission. The bigger the ferromagnetic sheet the closer to an ideal "image" and, thus, the larger WPT increase.

For a variant of said embodiment, the first and second outer surfaces of the wall of said only one ferromagnetic element of the second part are flat, said wall having a rectangular cross-section (forming for example a ferromagnetic sheet) and being
30 arranged parallel to the coil back surface, adjacent or in contact therewith.

For another embodiment, the wall of the only one ferromagnetic element of the second part has a wedge cross-section.

For another embodiment, the at least one ferromagnetic element of the second part comprises a plurality of ferromagnetic pieces electrically isolated with respect to
35 each other and arranged adjacent and coplanar to each other, such as ferromagnetic strips attached to each other by means of electrically isolating intermediate elements,

such that they constitute, for example, a sheet composed of ferromagnetic regions electrically isolated from each other. This embodiment is particularly thought for a case when the material used has some electrical conductivity, therefore being necessary to cut the ferromagnetic sheet into different pieces to reduce eddy currents and achieve the maximum WPT improvement.

A second aspect of the present invention relates to the use of the device of the first aspect for a high frequency range wireless power transmission, where frequency is in the order of a few MHz, preferably below 10 MHz, and more preferably above 3 MHz, where the device comprises the first part or the first part and the second part, the latter when comprising said several ferromagnetic elements.

A third aspect of the present invention relates to the use of the device of the first aspect for a low frequency range wireless power transmission, where frequency is in the order of KHz, preferably lower than 1000 KHz, and more preferably around 200 KHz

A fourth aspect of the present invention relates to a magnetic system to enhance wireless power transmission, comprising at least:

- a source of a magnetic field configured and arranged for generating a static magnetic field or an oscillating magnetic field, from an electrical signal delivered from an electrical power generator connected thereto, said source having a coil;
- a receiver of a magnetic field connected to an electrical battery for power charging the latter or to any circuit that stores or uses the received energy, and also having a coil; and
- at least one magnetic device according to the first aspect of the invention, wherein the coil over which the device is arranged or intended to be arranged is the coil of the source of a magnetic field or the coil of the receiver of a magnetic field, and the coils of the source and the receiver of a magnetic field and the magnetic device are arranged such that the magnetic field generated from the source of a magnetic field is directed towards the coil of the receiver of a magnetic field to power charge said electrical battery or to feed said circuit connected to the receiver with the wireless transmitted power.

For an embodiment, the system comprises at least two magnetic devices, each according to the first aspect of the invention, one of the magnetic devices for the coil of the source of a magnetic field and another of the magnetic devices for the coil of the receiver of a magnetic field.

Brief Description of the Drawings

The previous and other advantages and features will be better understood from the following detailed description of embodiments, with reference to the attached drawings, which must be considered in an illustrative and non-limiting manner, in which:

Fig. 1a schematically shows the device of the first aspect of the present invention
5 for an embodiment for which it is applied to the emitting coil, i.e. to the coil of the magnetic field source, and comprises a ferromagnetic part (in shaded) and a conductive part (in white) which is aligned with the emitting coil, such that the inner hole of this conductive part surrounds the coil.

Fig. 1b is an exploded view of the device of Fig. 1a.

10 Fig. 1c is a section view of device of Fig. 1b taken along a transversal and centred cut plane.

Fig. 2a schematically shows the device of the first aspect of the present invention for another embodiment which differs from the one of Fig. 1a in that the conductive part is placed under the emitting coil, being the hole of the conductive part larger than the
15 through-hole of the emitting coil but smaller than the external diameter of the coil.

Fig. 2b is an exploded view of the device of Fig. 2a.

Fig. 2c is a section view of device of Fig. 2b taken along a transversal and centred cut plane.

Fig. 3a schematically shows the device of the first aspect of the present invention
20 for an embodiment which differs from the one of Fig. 2a in that the ferromagnetic part is composed of several ferromagnetic elements constituted by respective walls arranged in parallel and distanced to each other, and perpendicularly with respect to the back surface of the emitting coil back and centred to the hole thereof.

Fig. 3b is an exploded view of the device of Fig. 3a.

25 Fig. 3c is a section view of the device of Fig. 3b taken along a transversal and centred cut plane.

Fig. 4a schematically shows the device of the first aspect of the present invention for an embodiment which differs from the one of Fig. 3a in that the several ferromagnetic elements are constituted by respective several cylindrical and concentric ferromagnetic
30 walls centred to the hole of the emitting coil.

Fig. 4b is an exploded view of the device of Fig. 4a.

Fig. 4c is a section view of the device of Fig. 4b taken along a transversal and centred cut plane.

Fig. 5a schematically shows the device of the first aspect of the present invention
35 for an embodiment which differs from the one of Fig. 3a in that the several ferromagnetic

walls are not arranged parallel to each other but according to different inclinations with respect to the shown vertical direction.

Fig. 5b is an exploded view of the device of Fig. 5a.

Fig. 5c is a section view of the device of Fig. 5b taken along a transversal and
5 centred cut plane.

Fig. 6a schematically shows the device of the first aspect of the present invention for an embodiment which differs from the one of Fig. 4a in that the several ferromagnetic elements are constituted by respective several concentric hollow frustrum ferromagnetic walls centred to the hole of the emitting coil.

10 Fig. 6b is an exploded view of the device of Fig. 6a.

Fig. 6c is a section view of the device of Fig. 6b taken along a transversal and centred cut plane.

Fig. 7a schematically shows the device of the first aspect of the present invention for an embodiment which differs from the one of Fig. 2a in that the ferromagnetic part is
15 cut into several pieces which are electrically insulated between them to minimize eddy currents and arranged adjacent and coplanar to each other.

Fig. 7b is an exploded view of the device of Fig. 7a.

Fig. 7c is a section view of the device of Fig. 7b taken along a transversal and centred cut plane.

20 Fig. 8 shows the device of the first aspect of the invention having only the ferromagnetic part, for different embodiments which are not part of the claimed invention, where the ferromagnetic part is implemented, from the left view to the right view, as shown respectively in Figures 3a, 4a, 7a and 1a (but for a ferromagnetic disk having a diameter similar to the external diameter of the coil).

25 Fig. 9 shows the device of the first aspect of the invention having only the conductive part, for different embodiments, where the conductive part is implemented, for the left view as shown in Fig. 1a, for the central view as shown in Fig. 2a, and for the right view as shown in Figure 2a but for a conductive part having two electrically insulating slits.

30 Fig. 10 shows, by means of a graph, the experimental results obtained with different experimental implementations of the device of the first aspect of the invention having as conductive part a copper disk of 100mm of diameter having four equidistant slits, alone or combined with a ferromagnetic part, and being applied on the source coil, according to different embodiments, the graph showing the improvement in the power
35 received by WPT at the receiver coil for high frequencies.

Fig. 11 shows a graph which differs from the one of Fig. 10 in that the conductive part used for the magnetic device is a copper disk having a 130mm diameter.

Fig. 12 is another graph, similar to the ones of Figs. 10 and 11 but for a copper square-shaped conductive part whose side length was 150mm and a centred circular hole of diameter 40mm.

Fig. 13 shows a graph which differs from the one of Fig. 12 in that the square-shaped conductive part used for the magnetic device has a larger side length, particularly of 300mm.

Fig. 14 also shows a graph showing the experimental results obtained with different experimental implementations of the device of the first aspect of the invention, in this case for a low frequency range, having only the ferromagnetic part.

Fig. 15 shows a further graph showing the experimental results obtained with different experimental implementations of the device of the first aspect of the invention, in this case also for a low frequency range, where the device has different conductive parts alone or combined with the ferromagnetic part.

Fig. 16 shows the circuit used to experimentally demonstrate the improvement on the WPT achieved with the magnetic device of the first aspect of the invention, for a first set of measurements.

Figure 17 shows the sketch of the setup used to perform a second set of measurements.

Figure 18 shows sketches of four different configurations G2 (a), G3 (b), G4 (c) and G5 (d) for the device of the first aspect of the invention used for the above mentioned second set of measurements.

Figure 19 shows the measured efficiency results as a function of the distance between the emitting and receiving coils and for the different configurations used for the second set of measurements, in linear (a) and logarithmic (b) scales.

Figure 20 is a graph showing the improvement achieved by the different configurations depicted in Figure 18 with respect to configuration G1, i.e. to the one shown in Figure 17.

Detailed Description of Several Embodiments

Figures 1 to 9 show different embodiment of the device of the first aspect of the invention applied to the coil L_s of the source of a magnetic field for enhancing the PWT towards the coil L_r of a receiver of the magnetic field. Said Figures also represent different embodiments of the magnetic system of the fourth aspect of the invention.

Although the device has been illustrated as applied to the emitter coil Ls, for other embodiments (not shown) it is applied also, or alternatively, to the receiver coil Lr.

Particularly, Figs. 1 to 9 show the magnetic device to enhance wireless power transmission of the first aspect of the invention, through magnetic coupling, between a source (or emitter) of a magnetic field and a receiver of a magnetic field, directing the magnetic field generated from the source to the region where the receiver is located, where the source and the receiver of a magnetic field have respective coils Ls, Lr facing each other by respective front surfaces Lsf, Lrf and having respective back surfaces Lsb, Lrb, where each pair of said front and back surfaces Lsf, Lsb; Lrf, Lrb are placed in respective opposite planes which are orthogonal to the magnetic axis of the coil Ls, Lr, each coil Ls, Lr also having a through-hole Os, Or extending between the front Lsf, Lrf and the back Lsb, Lrb surfaces, wherein the magnetic device is arranged over the emitter coil Ls.

For the embodiments of Figures 1-7 and 9, the device comprises a first part C, made of a material which is preferably an electrical conductor (copper, aluminium, etc.) and has a wall with first C1 and second C2 flat outer surfaces delimiting its thickness, said wall having a through-hole Oc traversing the thickness thereof, where the first flat outer surface C1 is arranged over the coil back surface Lsb with the wall through-hole Oc placed over the coil through-hole Os, Or, for Figures 2 to 7 and central and right views of Figure 9, or arranged aligned with the coil Ls such that the through-hole Oc of the first part C surrounds the coil Ls, for Figure 1 and left view of Fig. 9.

For other embodiments, not illustrated, only a portion of the first outer surface C1 is flat (the portion arranged over the coil back surface Lsb). The second outer surface C2 is flat, for an embodiment, but for other embodiments it is not flat.

As shown in said Figures 1-7 and 9, the first part C has one or more slits R extending from the through-hole Oc to an outer perimeter edge of the first part C, particularly one slit R for the embodiments of Figures 1 to 7 and left and central views of Figure 9, and two slits R for the embodiment of right view of Figure 9. Said slits R electrically isolate the portions of the first part C separated thereby.

Regarding the first part C, although it has been illustrated as a disk having a circular through-hole Oc, neither the external perimeter of the first part C nor the through-hole Oc have to be circular but can have other different shapes, for other embodiments. The through-hole Oc can be also asymmetric, for another embodiment.

For the embodiments of Figures 1 to 7 and 8, the magnetic device further comprises a second part comprising one or more ferromagnetic elements, in addition to

the first part C, for Figures 1 to 7, or without the first part C, for Figure 8. The embodiments of Figure 8 do not form part of the claimed invention.

Particularly, for the embodiment of Figs. 1 and 2 the second part comprises only a ferromagnetic element F, such a ferromagnetic sheet, having a wall with first F1 and second F2 flat outer surfaces delimiting its thickness, wherein the first outer surface F1 is arranged over the coil back surface Lsb (directly for Fig. 1 or, for Figs. 2 to 7, by being arranged over the conductive part C arranged in between, particularly over the second surface C2 thereof), covering the coil through-hole Os.

For other embodiments, not illustrated, only a portion of the first outer surface F1 (the portion arranged over the coil back surface Lsb) and/or of the second outer surface F2 of the ferromagnetic element F is/are flat.

For the embodiment of Figure 7, the ferromagnetic element F is composed of a plurality of ferromagnetic pieces Fc1-Fcn, such as strips, electrically isolated with respect to each other and arranged adjacent and coplanar to each other. Said ferromagnetic pieces Fc1-Fcn are illustrated in the cross section of Fig. 7c, schematically, as separated by air gaps, but they can be mounted on an electrically insulating support and/or attached to each other by electrically insulating strips.

For the embodiments of Figures 3, 4, 5 and 6, the second part comprises several ferromagnetic elements f in the form of respective walls with respective outer surfaces f1, f2 and arranged over the coil back surface Lsb (directly for Fig. 1 or, for Figs. 2 to 7, by being arranged over the conductive part C arranged in between, particularly over the second surface C2 thereof) in a transversal manner, such that said walls don't remain parallel to the coil back surface Lsb, with an upper edge fe of the walls being placed over a region occupied by the coil through-hole Os. Although in the Figures, the whole diameter of the coil through-hole Os is covered by the ferromagnetic walls f, if they are shifted such that only a part of the through-hole Os is covered, the magnetic device can also work, although in a less preferred mode.

For the embodiment of Figures 3 and 4, the ferromagnetic walls f remain perpendicular to the coil back surface Lsb, and while in Fig. 3 the first f1 and second f2 outer surfaces of the several ferromagnetic walls f are flat and arranged adjacent and parallel to each other, in Fig. 4 the ferromagnetic walls f are cylindrical walls arranged concentrically to each other.

Fig. 5 illustrates another embodiment in which the ferromagnetic walls f are also flat but not arranged parallel to each other but according to different inclinations with respect to the shown vertical direction.

In the embodiment of Fig. 6, the walls of the several ferromagnetic elements f of the second part have respective hollow frustrum shapes, and each of them is introduced, by its smaller base, into the hollow inner space of an adjacent hollow frustrum-shaped wall f , concentrically to each other.

5 As mentioned above, Fig. 8 shows the magnetic device of the first aspect of the invention having only the ferromagnetic part, for different embodiments which are not part of the claimed invention, where the ferromagnetic part is implemented, from the left view to the right view, as shown respectively in Figures 3a, 4a, 7a and 1a, the latter for a ferromagnetic disk having a diameter similar to the external diameter of the coil.

10

Experimental tests:

First set of measurements:

The improvement on the WPT using the magnetic device of the first aspect of the invention for different arrangements has been experimentally confirmed, as will be detailed below, for two frequency ranges: high frequencies and low frequencies.

15

- High frequencies ($10\text{MHz} > f > 3\text{MHz}$):

Two identical coils of 8 turns were used, as L_s and L_r , with inner and outer diameters of 37 and 66mm respectively. Their measured self-inductances at around 20 4MHz were $(3.8 \pm 0.2) \cdot 10^{-6}$ H.

The circuit used to experimentally demonstrate the improvement on the WPT is sketched in Fig. 16. A sinusoidal signal generator (with an internal resistance $R_{in}=50\Omega$) was connected to the emitter coil L_s . The signal frequency was set to 3.791MHz. The receiver coil L_r was connected in parallel to a capacitor $C=0.33\text{nF}$ and a load resistance 25 R_L . The voltage signal between points a and b was plotted and its amplitude V_R was measured.

First, it was measured V_R as a function of the distance d between the two coils alone (V_R^{alone}). Then, it was measured again using the magnetic device of the present invention (V_R^{device}). The improvement provided by the device was calculated as $(V_R^{\text{device}} - 30 V_R^{\text{alone}})/V_R^{\text{alone}} \cdot 100$.

These measurements were done for two different load resistances $R_L=1800\Omega$ and $R_L=1\text{M}\Omega$. Improvements achieved by some arrangements of the magnetic device of the invention are shown in Figs. 10 to 13, where $R_{out} = 33\text{mm}$ refers to the external radius of the emitter coil L_s (and, in this case, also of the receiver coil L_r).

The first arrangement was similar to the one shown in the right view of Fig. 9, where the first part C was a copper disk of 100mm consisted of a conductive part made of copper foil (0.35mm thick), with a circular external shape with a diameter of 100mm and a centred circular hole of diameter 40mm, but, in contrast to the embodiment shown in the right view of Fig. 9, it had four equidistant slits R. Measurements using only this
5 conductive part are shown in empty symbols in Fig. 10.

Then a ferromagnetic (FM) part was added and the improvement achieved by the complete device (conductive part + FM) was measured, shown in solid symbols in Fig. 10. The FM part was made of 6 pieces of ferrite sheet (0.3mm thick) of approximate
10 size 60x30mm parallel displaced with a gap of 5mm between them. It was placed behind the conductive part as sketched in Fig. 3a.

These measurements were repeated with a second arrangement, where the only difference was that the conductive part had an external circular shape of 130mm (it also had 4 slits). First, the magnetic device with the conductive part only (empty symbols in
15 Fig. 11) was measured and then the device with the conductive part and the same FM part as before (solid symbols in Fig. 11).

The third arrangement that was built and measured had a square-shaped conductive part whose side length was 150mm. It had a centred circular hole of diameter 40mm and it also had 4 slits. Measurement results of the conductive part and
20 conductive part + FM are shown in Fig. 12. The FM part was also the one shown in Fig. 3a.

The fourth arrangement was similar to the third one but with a larger side length of 300mm for the conductive part. Measurement results are shown in Fig.13. The FM part was also the one shown in Fig. 3a.

From these measurements it is shown that the larger the conductive piece, the larger the improvement obtained. This behaviour can be physically understood taking into account that the conductive part tends to change the magnetic field distribution created by the coil from a dipolar form (the typical field of a coil) to a monopolar form. A dipolar field distribution rapidly decays with the distance (d) between the emitter and the
30 measuring point as $\sim d^{-3}$. Differently, the monopolar distribution decays more slowly as $\sim d^{-2}$. For this reason, comparing the WPT for the case of the bare coils and when using the magnetic device of the first aspect of the invention, the latter is always larger and the improvement increases as the coils are placed farther away.

It can be shown that the field distribution changes from a dipolar to a monopolar
35 form assuming ideal conditions and only when the conductive part extends to the

infinite. For this reason, the larger the conductive part, the more monopolar the field distribution, and therefore, the larger improvement obtained by the device.

- Low frequencies ($f < 1000\text{KHz}$):

5 It was experimentally confirmed the improvement on the WPT using the above described designs for the magnetic device of the first aspect of the invention, for low frequencies. In this two commercial coils made by TDK® (WR444030-16F3-G) were used, which are approved for the Qi standard. These coils are approximately square-shaped, with a side length of 40mm and a squared hole whose side length is 23mm. Its
10 self-inductance at 100KHz is 19.0 μH .

The circuit used to experimentally demonstrate the improvement on the WPT at low frequencies was also the one sketched in Fig. 16. A sinusoidal signal generator (with an internal resistance $R_{in}=50\Omega$) was connected to the emitter coil L_s . In this case a ferrite sheet that was glued to the back of the emitting coil L_s was removed. The signal
15 frequency was set to 177KHz. The receiver coil L_r was connected in parallel to a capacitor $C=43.1\text{nF}$ and a load resistance $R_L=1\text{M}\Omega$. In this case a ferrite sheet that was glued to the receiving coil L_r was kept. The voltage signal between points a and b was plotted and its amplitude V_R was measured. First, V_R as a function of the distance d between the two coils alone (V_R^{alone}) was measured. Then, measurements were made
20 again using different arrangements of the magnetic device of the first aspect of the invention (V_R^{device}). The improvement provided by the device was calculated as $(V_R^{\text{device}} - V_R^{\text{alone}}) / V_R^{\text{alone}} \cdot 100$.

First, the improvement provided by the FM part alone was measured. Four different FM parts were used: FM1 was a square ferrite sheet of 120x120mm and a
25 thickness of 0.2mm with a relative magnetic permeability around 240; FM2 was a square ferrite sheet of 120x120mm and a thickness of 0.3mm with a relative magnetic permeability around 110; FM3 was a circular ferrite sheet of diameter 50mm and thickness 1mm; FM4 was the same FM part used in the high frequency measurements. It was made of 6 pieces of ferrite sheet (0.3mm thick) of approximate size 60x30mm
30 parallel displaced with a gap of 5mm between them. It was placed with the pieces perpendicularly arranged to the coil surface (like in Fig. 8, left view, but for a square coil L_s). Results are shown in Fig. 14, where $R_{out} = 20\text{mm}$ refers to the external radius of the emitter coil L_s (and, in this case, also of the receiver coil).

Measurements show that using only a FM part improves the WPT. Comparing
35 FM1 and FM2 it can be seen how the transfer improves increasing the FM permeability. In addition, as already explained above, the larger the FM the larger improvement

achieved (compare FM1 and FM3). The FM4, despite its small size compared with FM1 and FM2, achieves relevant improvement factors, especially when the coils L_s and L_r are one far from each other.

Then, the improvement achieved by the conducting parts alone was measured.

5 Two different conducting parts, Cu1 and Cu2 were tested. Cu1 was made of copper foil (0.35mm thick) and had an approximately square external shape of 61x57mm. It had a centred hole of size 22x26mm and had 4 slits. Cu2 had a similar geometry with a bigger external shape of 101x97mm. The improvement achieved by these parts is shown in Fig. 15, in solid and empty square symbols. Notice that the bigger the conductive part,

10 the larger the improvement obtained; following the same behaviour as for the high frequency cases and tending to modify the field distribution from a dipolar to a monopolar form.

Finally, the improvement obtained when the two parts (the FM and the conductive part) are used together was measured. The conductive part Cu1 was

15 combined with the small circular FM3 and also with the FM4. In this case the latter combination achieves slightly better improvements on the WPT. Notice that using the two parts together leads to improvements significantly larger than those obtained with the two separated parts, in particular at large distances d/R_{out} .

The conductive part Cu2 was combined with the FM sheet FM1 and also with

20 FM4. In this case the former combination achieved the larger improvements, but it has to be taken into account that FM1 was larger than the FM4.

Second set of measurements:

The improvement on the wireless power transfer (WPT) provided by the device

25 of the first aspect of the invention was submitted to a second set of measurements. Results are expressed in terms of the efficiency of the transfer, which is the usual figure of merit [5, 9].

Two identical coils of 8 turns were used, with inner and outer diameters of 37 and 66mm, respectively. Their measured self-inductances at around 4MHz were $(3.8 \pm 0.2) \cdot 10^{-6}$ H. The circuit used to experimentally demonstrate the improvement on the WPT is

30 sketched in Fig. 17. A first coil, emitter coil L_s , was connected to a primary circuit consisting of a signal generator and a power amplifier, in series with a shunt resistance R_s . The second coil, receiver coil L_r , was connected in parallel to a capacitor, $C = 0.329$ nF, and a load resistance, $R_L = 985 \Omega$, forming a resonant secondary circuit. The

35 total power delivered to the system, W_T , and the power dissipated in the load resistance, W_{RL} , are calculated through [10]

$$W_T = \frac{V_a V_b}{2R_s} \cos \phi_{a \rightarrow b}, \quad W_{RL} = \frac{1}{2} \frac{V_{RL}^2}{RL}, \quad (1)$$

where V_a (V_b) is the amplitude of the voltage at point a (b), $\phi_{a \rightarrow b}$ the phase shift between the voltages at points a and b , and V_{RL} the amplitude of the voltage drop in the load resistance (see Fig. 17). Finally, the efficiency of the transfer, η , is calculated as
 5 [9].

$$\eta = \frac{W_{RL}}{W_T}. \quad (2)$$

Five different measurements were performed:

(i) First, the WPT between the two bare coils L_s , L_r was measured as a function of the distance d between them (configuration G1, shown in Figure 17). The frequency of the signal generator was fixed at the resonance frequency of the secondary circuit f
 10 $=4.047\text{MHz}$.

(ii) Then, a conductive part C (configuration G2, see Fig. 18a) was placed behind the emitting coil L_s . This part C was a square-shaped flat piece made of conductive foil (0.35mm thick) whose side length was 150mm. It had a centred circular hole of diameter
 15 40mm and had 4 slits R . Measurements of WPT were repeated at the same frequency.

(iii) A ferromagnetic part f was added behind the conductive part C in the emitting coil L_s (configuration G3, see Fig. 18b). This ferromagnetic part f was made of 6 pieces of ferrite sheet (0.3mm thick) of approximate size 60x30mm parallel displaced with a gap of 5mm between them. Measurements were repeated at the same frequency.

(iv) Next, a conductive part C was added behind the receiving coil L_r (configuration G4, see Fig. 18c). This part C was a disk of 130mm of diameter made of conductive foil (0.35mm thick), with a centred circular hole of diameter 40mm and had four slits R . Measurements were repeated at the new resonance frequency of the secondary circuit f
 20 $=4.284\text{MHz}$.

(v) Finally, a ferromagnetic part F made of ferrite sheet with a rectangular shape of 95x28mm was placed behind the conductive part C of the receiving coil L_r (configuration G5, see Fig. 18d). The new resonance frequency was f
 25 $=4.096\text{MHz}$.

The results of this second set of measurement are shown in Fig. 19, where the efficiency of the transfer is plotted as a function of the distance d between the coils L_s and L_r (being $R_{out} = 33\text{mm}$, the external radii of the coils). They show how all the configurations G2 to G5, i.e. those including the device of the first aspect of the invention, improve the transfer efficiency of the bare coils (configuration G1), achieving
 30 very significant results with configurations G4 and G5. The ratio of improvement

provided by the different configurations respect to the bare coils (configuration G1) is shown in Fig. 20.

A person skilled in the art could introduce changes and modifications in the embodiments described without departing from the scope of the invention as it is defined
5 in the attached claims.

Claims

1.- A magnetic device to enhance wireless power transmission, through magnetic coupling, between a source of a magnetic field and a receiver of a magnetic field, directing the magnetic field generated from the source to the region where the receiver is located, said source and said receiver of a magnetic field having respective coils (Ls, Lr) facing each other by respective front surfaces (Lsf, Lrf) (8) and having respective back surfaces (Lsb, Lrb), where each pair of said front and back surfaces (Lsf, Lsb; Lrf, Lrb) are placed in respective opposite planes which are orthogonal to the magnetic axis of the coil (Ls, Lr), each coil (Ls, Lr) also having a through-hole (Os, Or) extending between the front (Lsf, Lrf) and the back (Lsb, Lrb) surfaces, wherein the magnetic device is intended to be arranged over one of said coils (Ls, Lr) and is **characterised** in that it comprises a first part (C), made of a material which is an electrical conductor or at least partially diamagnetic with diamagnetism as its main contribution to magnetism, said first part (C) being or having a wall with first (C1) and second (C2) outer surfaces delimiting its thickness, said wall having a through-hole (Oc) traversing the thickness thereof, a flat portion of said first outer surface (C1) surrounding said wall through hole (Oc) and being configured and intended to be arranged over said coil back surface (Lsb, Lrb) with said wall through-hole (Oc) placed, at least in part, over the coil through-hole (Os, Or), or to be arranged substantially aligned with one of said front (Lsf, Lrf) and back (Lrb, Lrb) surfaces of the coil (Ls, Lr) or with a parallel plane sandwiched between the coil front (Lsf, Lrf) and back (Lrb, Lrb) surfaces such that the through-hole (Oc) of the first part (C) surrounds the coil (Ls, Lr), wherein said first part (C) has at least one slit (R) extending from the through-hole (Oc) to an outer perimeter edge of the first part (C).

2.- The device of claim 1, further comprising a second part comprising at least one ferromagnetic element (F, f) being or having a wall with first (F1, f1) and second (F2, f2) outer surfaces delimiting its thickness, wherein:

- a flat portion of said first outer surface (F1) being configured and intended to be arranged over said coil back surface (Lsb, Lrb) covering the coil through-hole (Os, Or), at least in part; or
- said at least one ferromagnetic element is one of several ferromagnetic elements (f) being or having respective walls configured and intended to be arranged over the coil back surface (Lsb, Lrb) in a transversal manner, such that said walls don't remain parallel to the coil back surface (Lsb, Lrb), with at least part of an upper edge (fe) of said walls being placed over at least a region occupied by said coil through-hole (Os, Or).

3.- The device of claim 1 or 2, further comprising said coil (Ls, Lr) of said source or of said receiver of a magnetic field, wherein the flat portion of the first outer surface (C1) of the wall of the first part (C) is arranged over the coil back surface (Lsb, Lrb) with the wall through-hole (Oc) placed over the coil through-hole (Os, Or) or arranged
5 substantially aligned with one of the front (Lsf, Lrf) and back (Lsb, Lrb) surfaces of the coil (Ls, Lr) or with a parallel plane sandwiched between the coil front (Lsf, Lrf) and back (Lrb, Lrb) surfaces such that the through-hole (Oc) of the first part (C) surrounds the coil (Ls, Lr).

4.- The device of claim 3 when depending on claim 2, wherein the flat portion of
10 the first outer surface (F1) of the wall of the at least one ferromagnetic element (F) of the second part is arranged over the coil back surface (Lsb, Lrb) covering the coil through-hole (Os, Or) or the walls of the several ferromagnetic elements (f) are arranged over the coil back surface (Lsb, Lrb) in a transversal manner, such that the walls don't remain parallel to the coil back surface (Lsb, Lrb), with at least part of an upper edge (fe) of the
15 walls being placed over at least a region occupied by the coil through-hole (Os, Or).

5.- The device of any of the previous claims, wherein said first part (C) comprises two or more of said slits (R) extending from the through-hole (Oc) to different parts of the outer perimeter edge of the first part (C), such that different portions of the first part (C) are defined which are electrically isolated with respect to each other.

20 6.- The device of claim 5, further comprising a support, made of an electrically isolating material, to which said different portions of the first part (C) are attached.

7.- The device of any of the previous claims, wherein said at least one slit (R) is open to air or filled with an electrically isolating material.

25 8.- The device of any of the previous claims, wherein said coil (Ls, Lr) is a planar coil.

9.- The device of any of the previous claims, wherein at least said flat portion of the first outer surface (C1) of the wall of the first part (C) is arranged or to be arranged adjacent to said coil back surface (Lsb, Lrb) or in contact therewith.

30 10.- The device of any of the previous claims, wherein the size of the through-hole (Oc) of the first part (C) is substantially equal, in size, or larger than the size of the through-hole (Os, Or) of the coil (Ls, Lr).

11.- The device of any of the previous claims, wherein the through-hole (Oc) of the first part (C) and the through-hole (Os, Or) of the coil (Ls, Lr) are substantially coaxial.

35 12.- The device of claim 2 or of any of claims 3 to 11 when depending on claim 2, wherein at least one of the first (f1) and second (f2) surfaces of the walls of the several

ferromagnetic elements (f) of the second part, when arranged over the coil back surface (Lsb, Lrb), remain perpendicular thereto.

13.- The device of claim 2 or of any of claims 3 to 11 when depending on claim 2, wherein the first (f1) and second (f2) outer surfaces of the walls of said several
5 ferromagnetic elements (f) of the second part are flat, said walls being arranged adjacent and parallel to each other.

14.- The device of claim 2 or of any of claims 3 to 12 when depending on claim 2, wherein the walls of said several ferromagnetic elements (f) of the second part are cylindrical walls arranged concentrically to each other.

10 15.- The device of claim 2 or of any of claims 3 to 12 when depending on claim 2, wherein the walls of said several ferromagnetic elements (f) of the second part have respective hollow frustrum shapes, and each of them is at least partially introduced, by its smaller base, into the hollow inner space of an adjacent hollow frustrum-shaped wall, concentrically to each other.

15 16.- The device of claim 2 or of any of claims 3 to 15 when depending on claim 2, wherein said at least one ferromagnetic element (F, f) is made of a soft ferromagnetic material, with a large relative magnetic permeability, greater than 10, and a low electric conductivity, smaller than $2 \cdot 10^6$ S/m.

17.- The device of claim 2 or of any of claims 3 to 16 when depending on claim 2,
20 wherein said at least one ferromagnetic element (F) of the second part is only one ferromagnetic element (F).

18.- The device of claim 17, wherein the first (F1) and second (F2) outer surfaces of the walls of said only one ferromagnetic element (F) of the second part are flat, said walls having a rectangular cross-section and being arranged parallel to the coil back
25 surface (Lsb, Lrb), adjacent or in contact therewith.

19.- The device of claim 2 or of any of claims 3 to 15 when depending on claim 2, wherein said at least one ferromagnetic element (F) of the second part comprises a plurality of ferromagnetic pieces (Fc1-Fcn) electrically isolated with respect to each other and arranged adjacent and coplanar to each other.

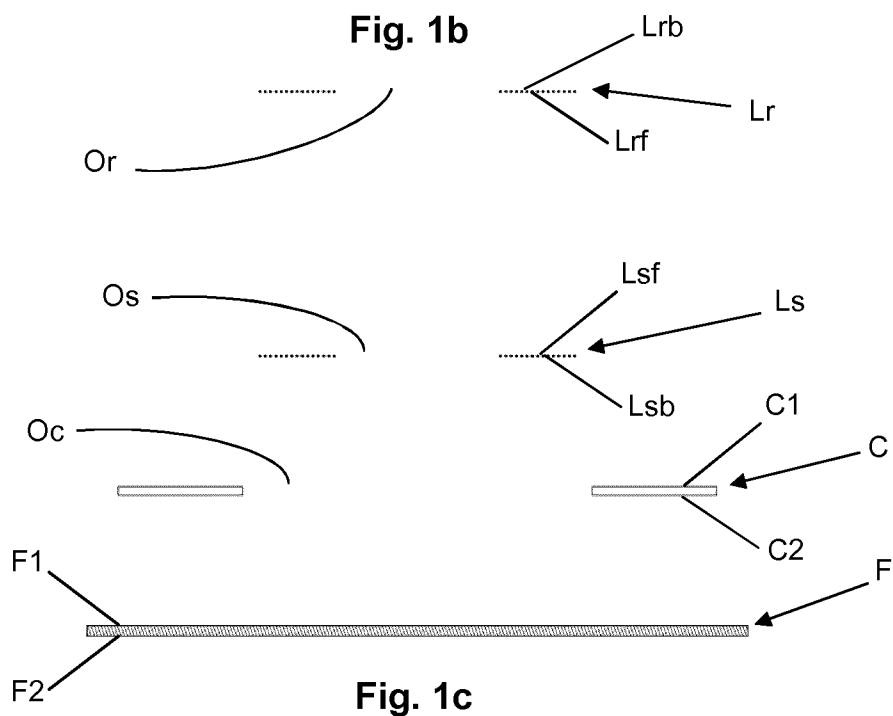
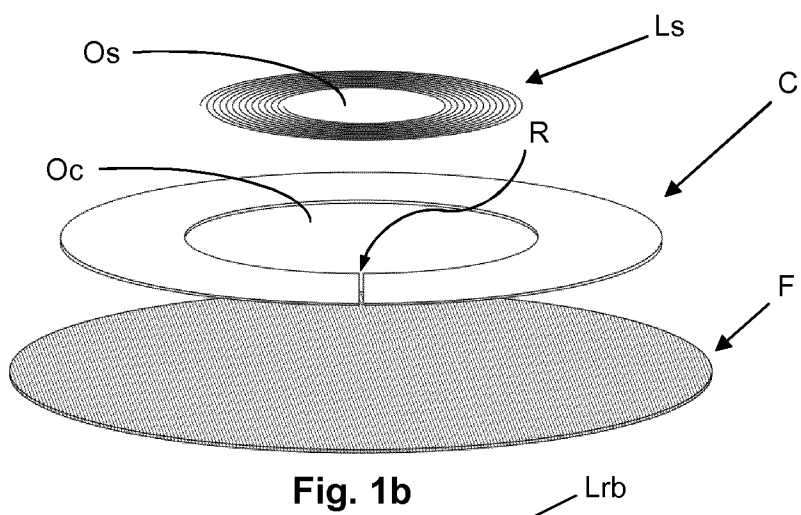
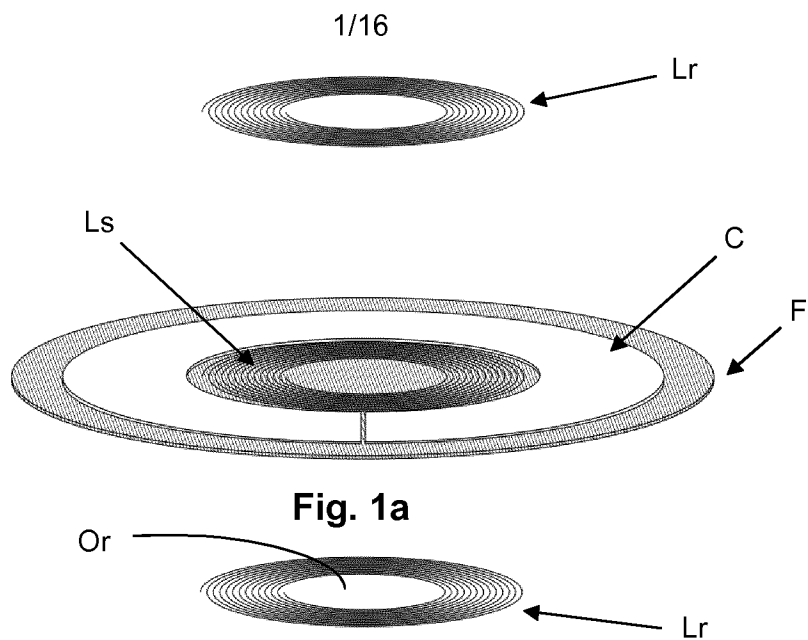
30 20.- The device of claim 2 or of any of claims 3 to 19 when depending on claim 2, wherein said ferromagnetic elements (F, f) are ferromagnetic sheets.

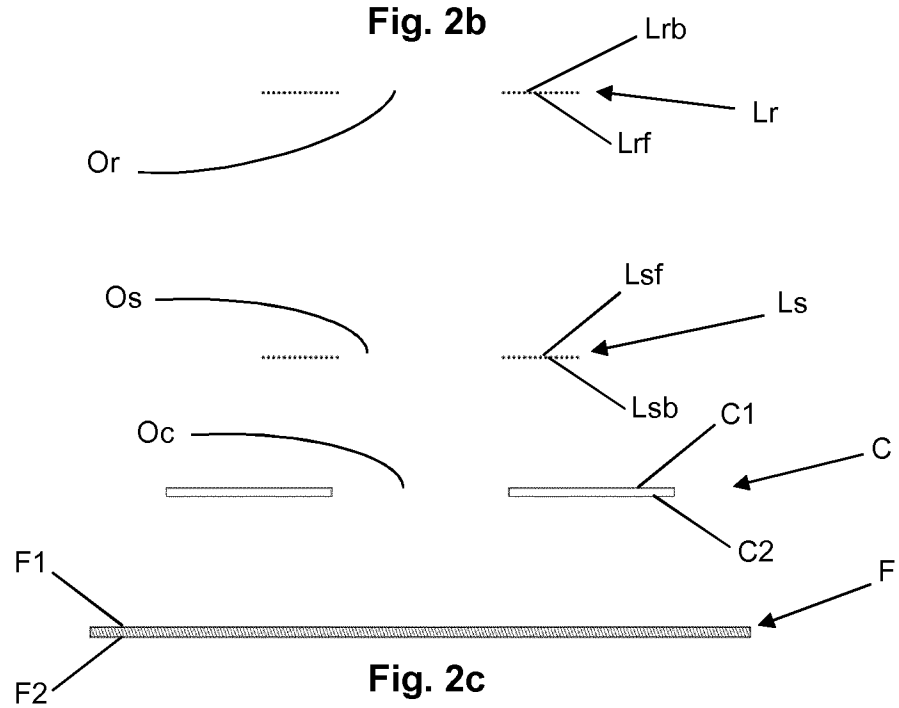
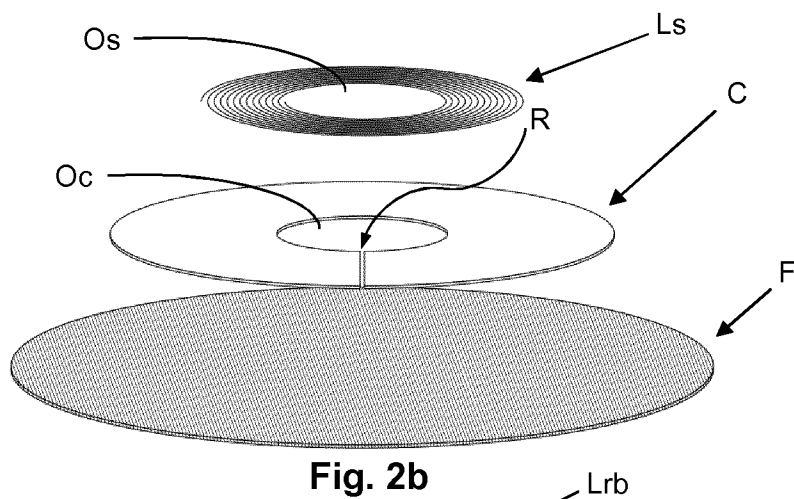
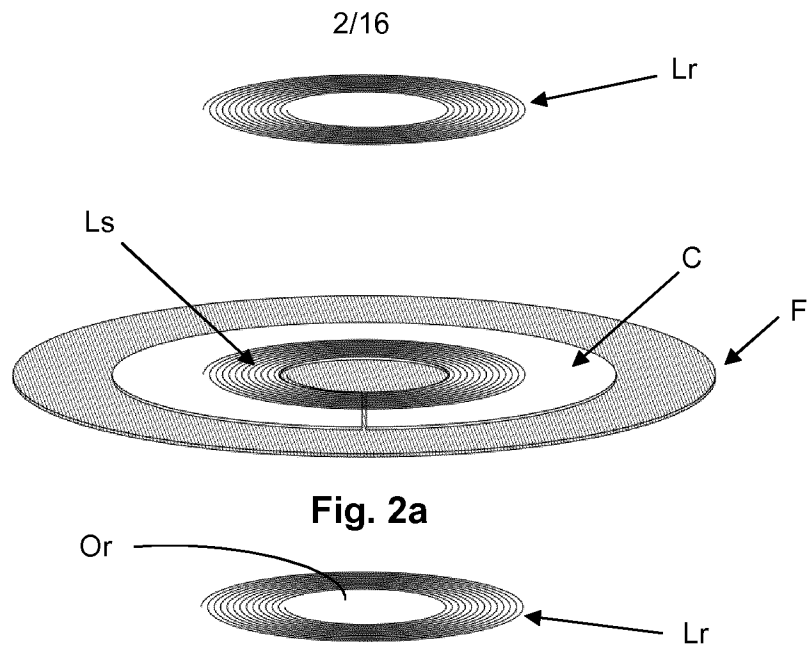
21.- Use of the device of any of the previous claims except for claims 17 to 19, for a high frequency range wireless power transmission, where frequency is in the order of a few MHz, preferably below 10 MHz, where the device comprises said first part (C)
35 or said first part (C) and said second part, the latter comprising said several ferromagnetic elements (f).

22.- Use of the device of any of claims 1 to 20, for a low frequency range wireless power transmission, where frequency is in the order of KHz, preferably lower than 1000 KHz.

23.- A magnetic system to enhance wireless power transmission, comprising at least:

- a source of a magnetic field configured and arranged for generating a static magnetic field or an oscillating magnetic field, from an electrical signal delivered from an electrical power generator connected thereto, said source having a coil (Ls);
 - a receiver of a magnetic field connected to an electrical battery for power charging the latter or to any circuit that stores or uses the received energy, and also having a coil (Lr); and
 - at least one magnetic device according to any of claims 1 to 20, wherein the coil over which the device is arranged or intended to be arranged is said coil (Ls) of the source of a magnetic field or said coil (Lr) of the receiver of a magnetic field, and wherein the coils (Ls, Lr) of the source, the receiver of a magnetic field and the magnetic device are arranged such that the magnetic field generated from the source of a magnetic field is directed towards the coil (Lr) of the receiver of a magnetic field to power charge said electrical battery or to feed said circuit connected to the receiver with the wireless transmitted power.
- 24.- The system of claim 23, comprising at least two magnetic devices, each according to any of claims 1 to 20, one of the magnetic devices for the coil (Ls) of said source of a magnetic field and another of the magnetic devices for the coil (Lr) of said receiver of a magnetic field.





3/16

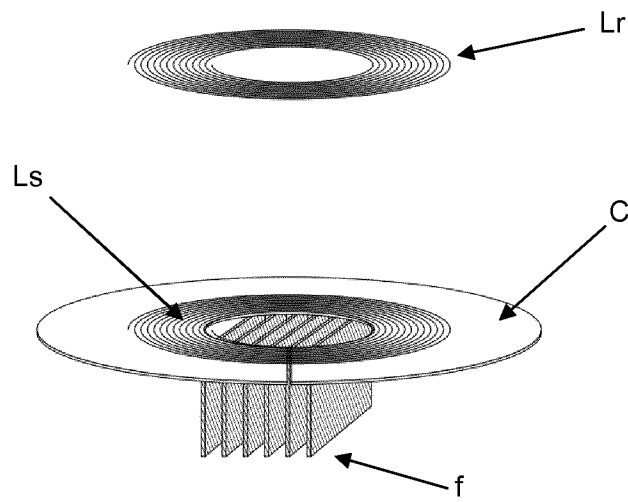


Fig. 3a

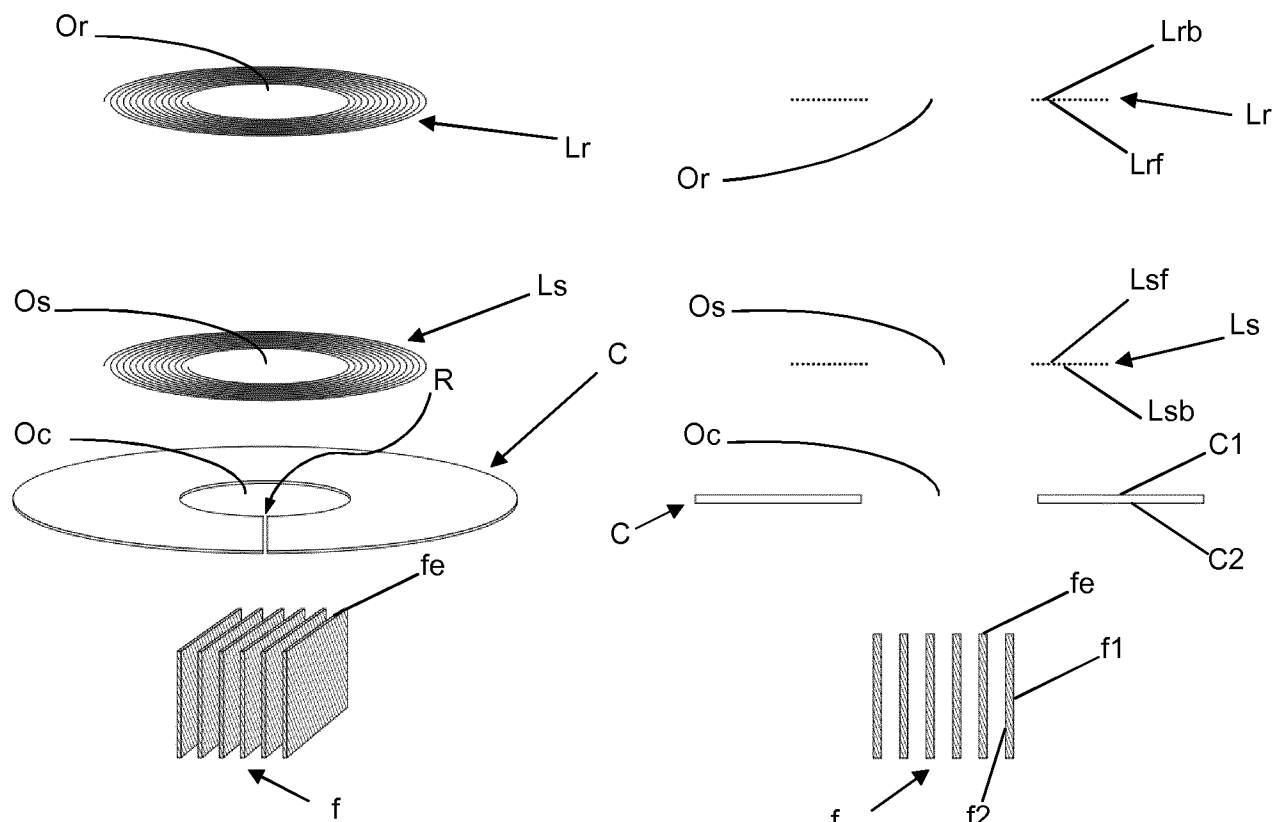


Fig. 3b

Fig. 3c

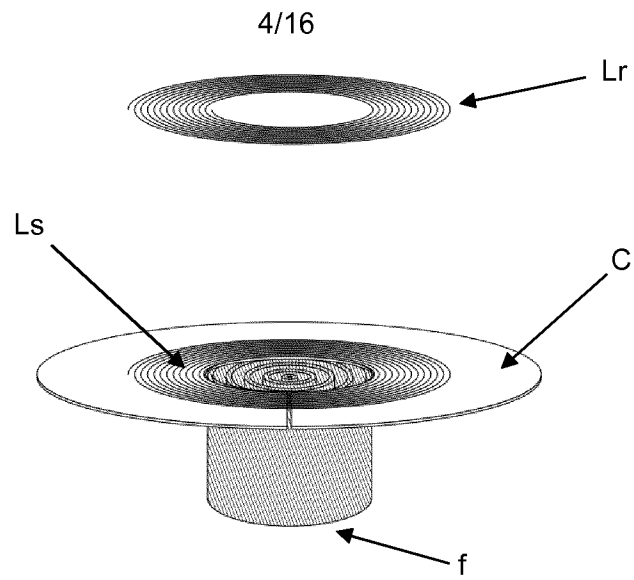


Fig. 4a

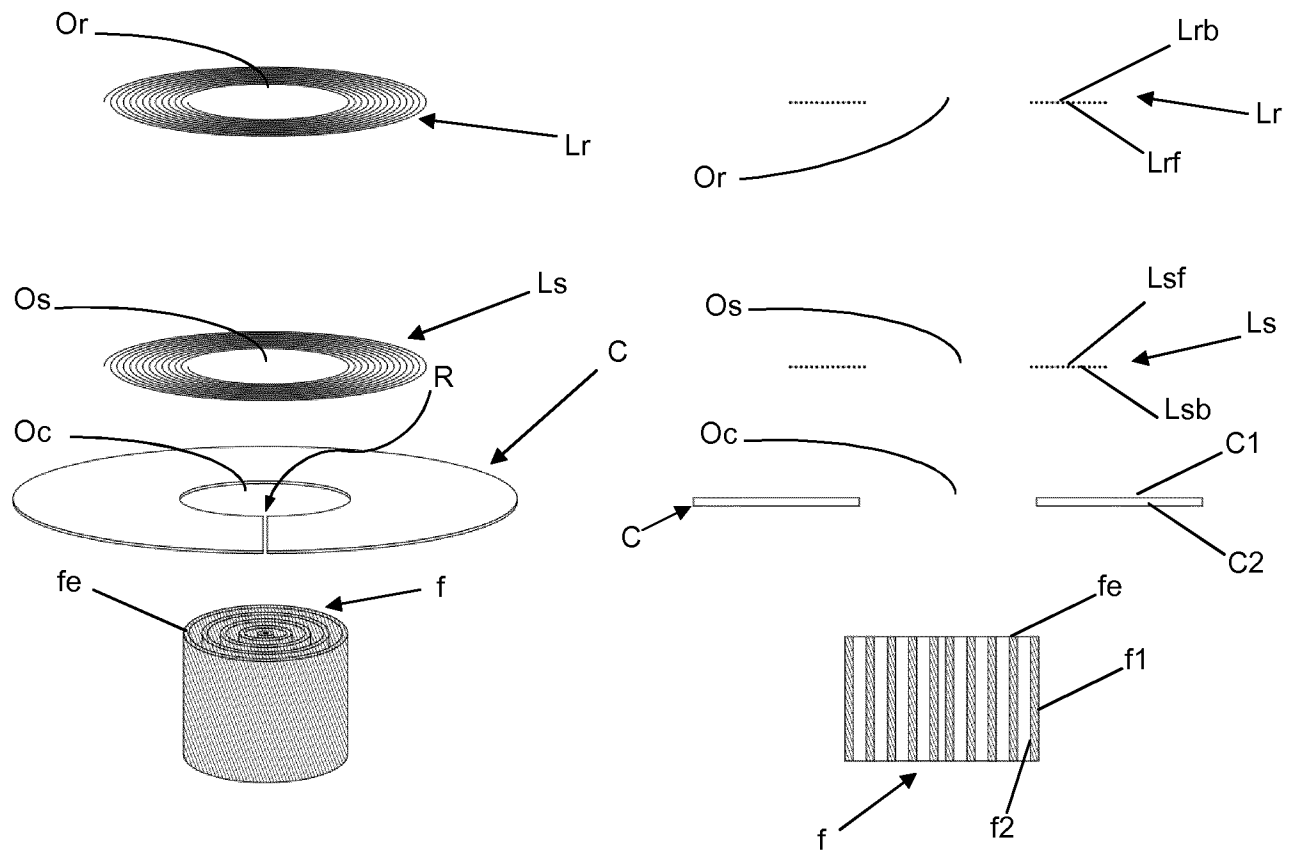


Fig. 4b

Fig. 4c

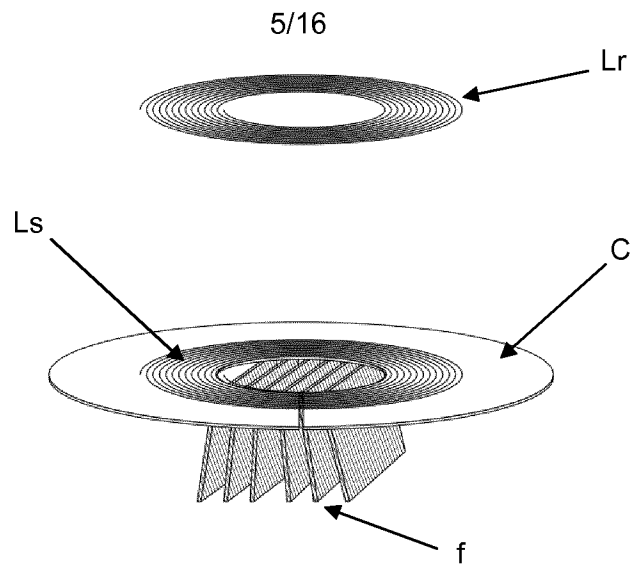


Fig. 5a

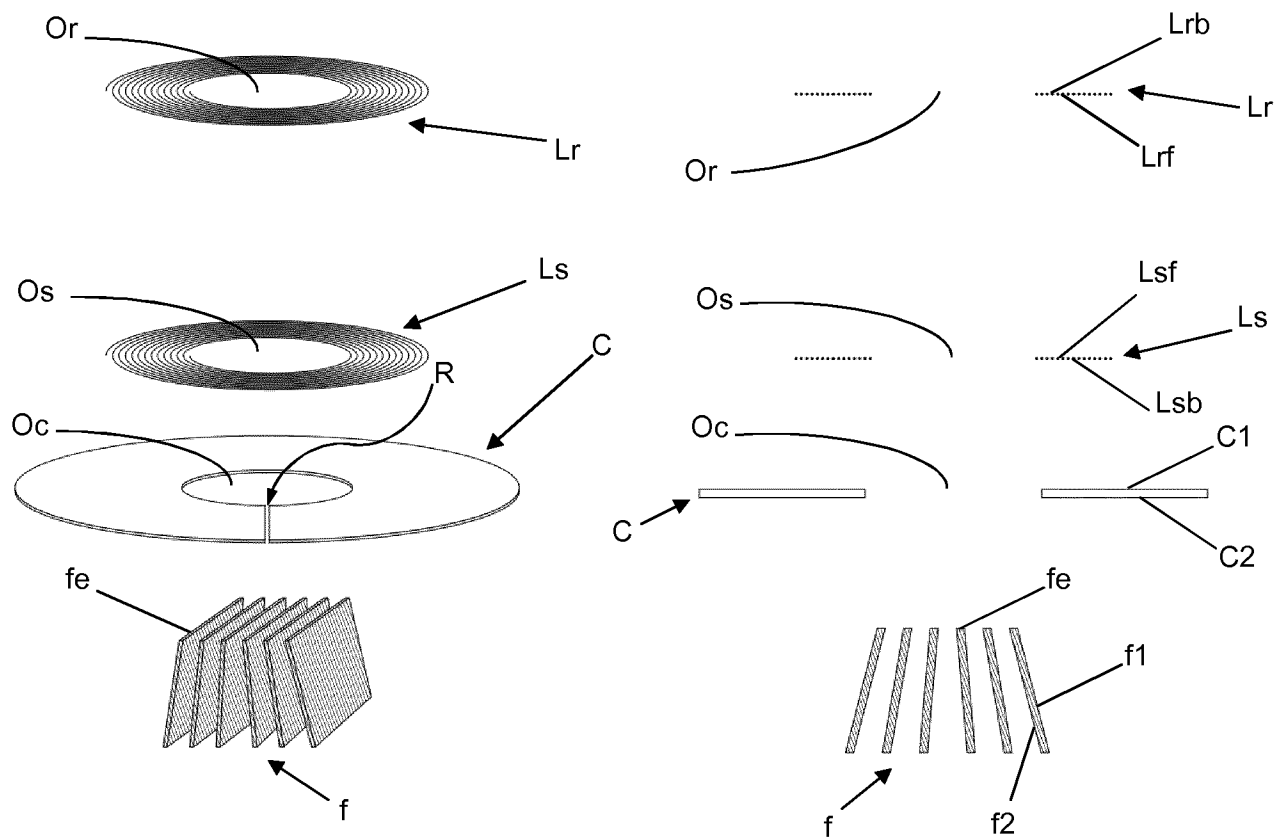
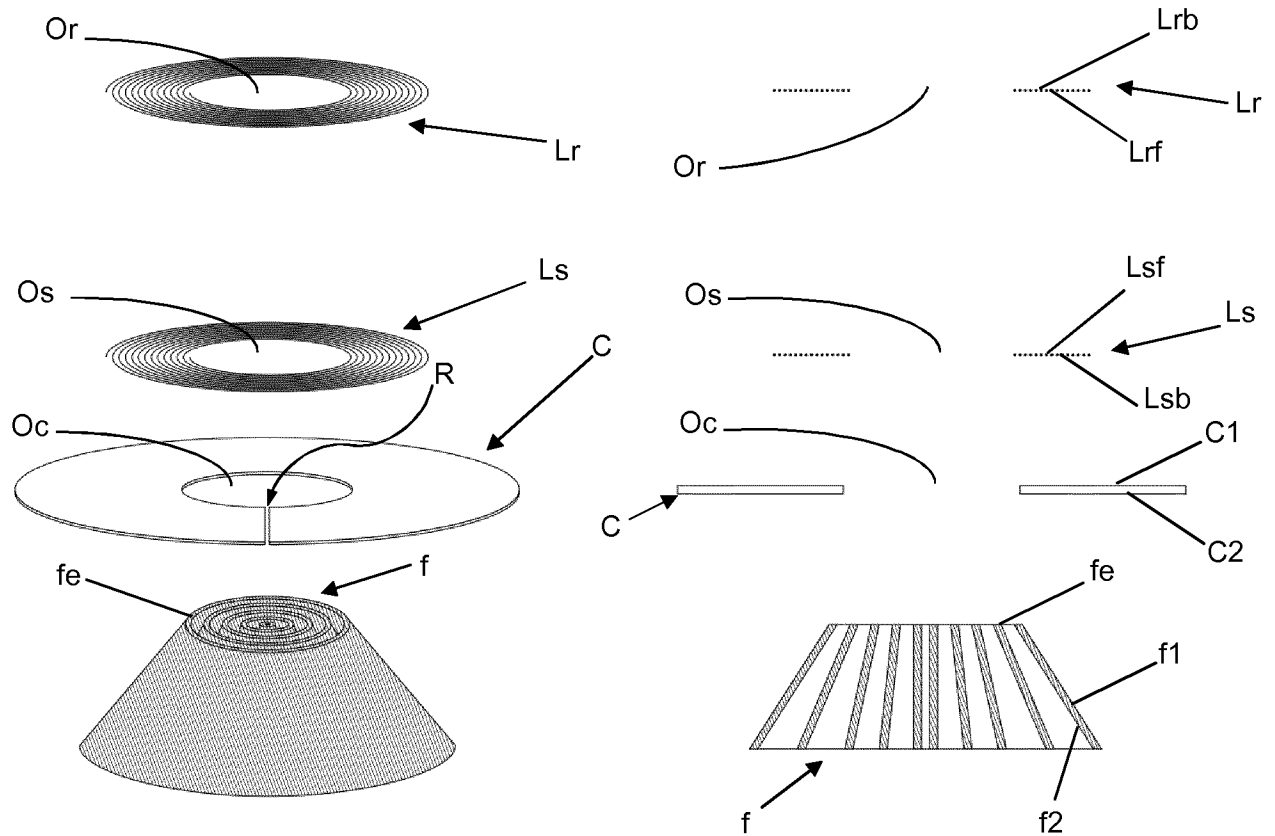
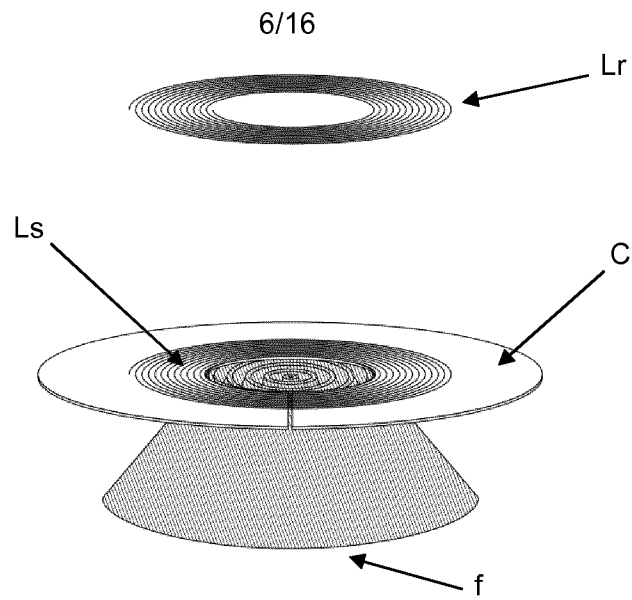


Fig. 5b

Fig. 5c



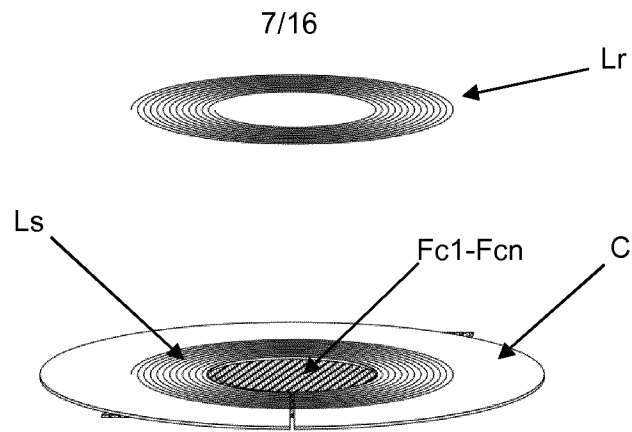


Fig. 7a

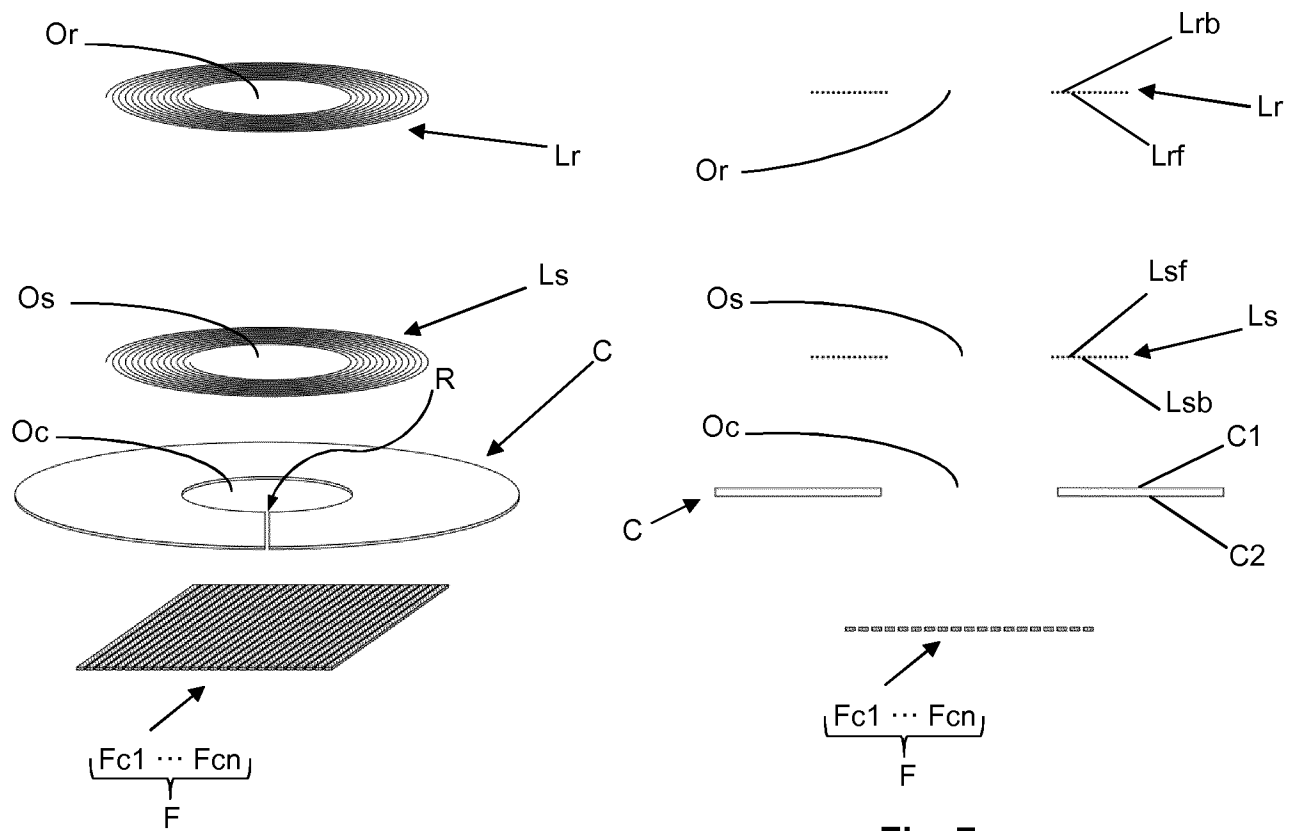


Fig. 7b

Fig. 7c

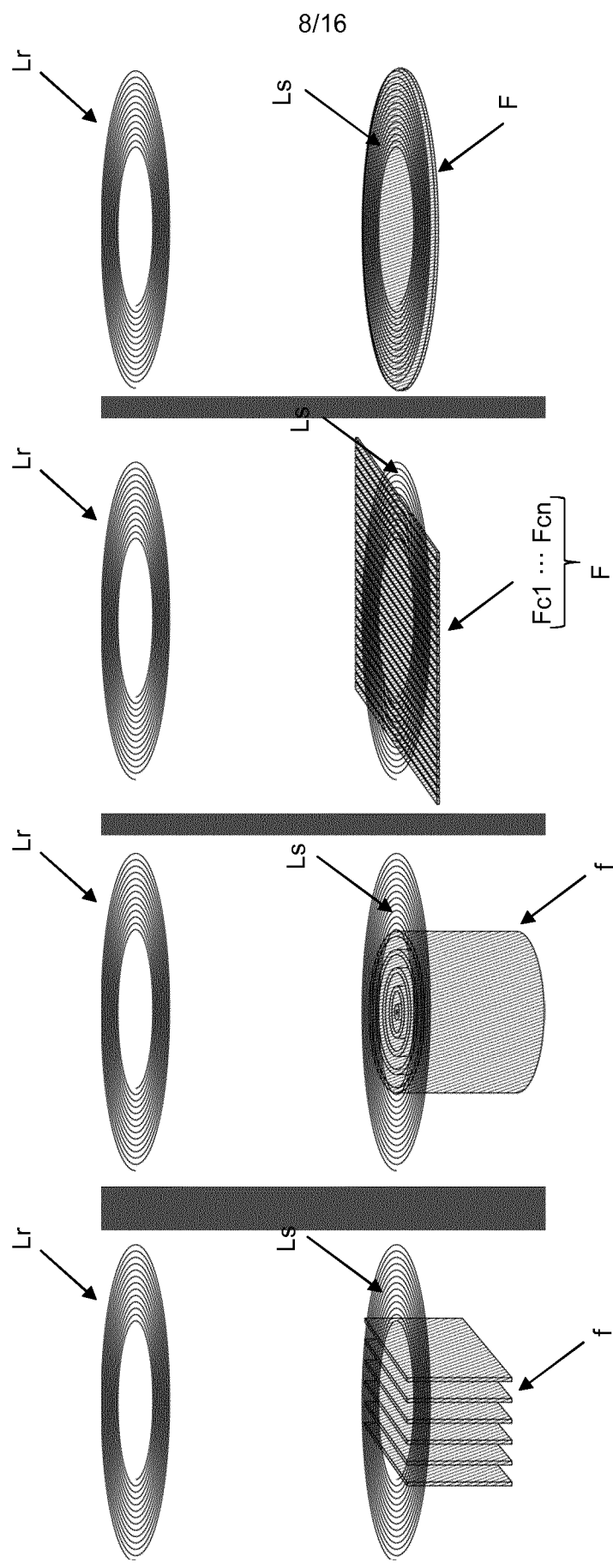


Fig. 8

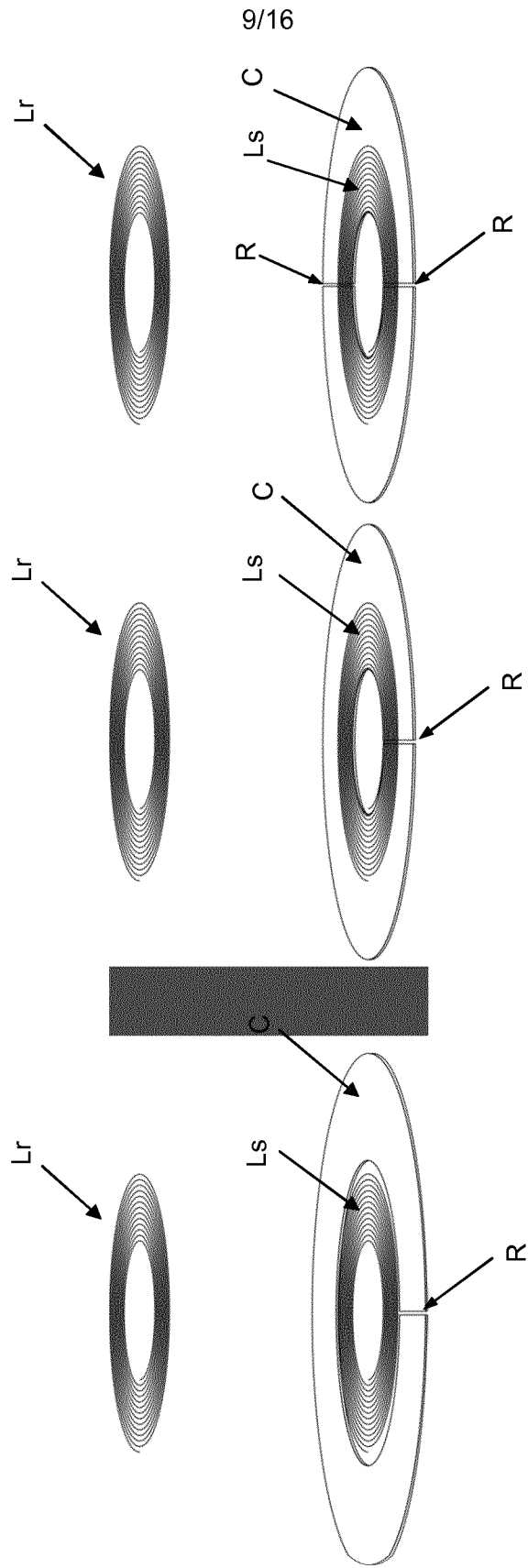


Fig. 9

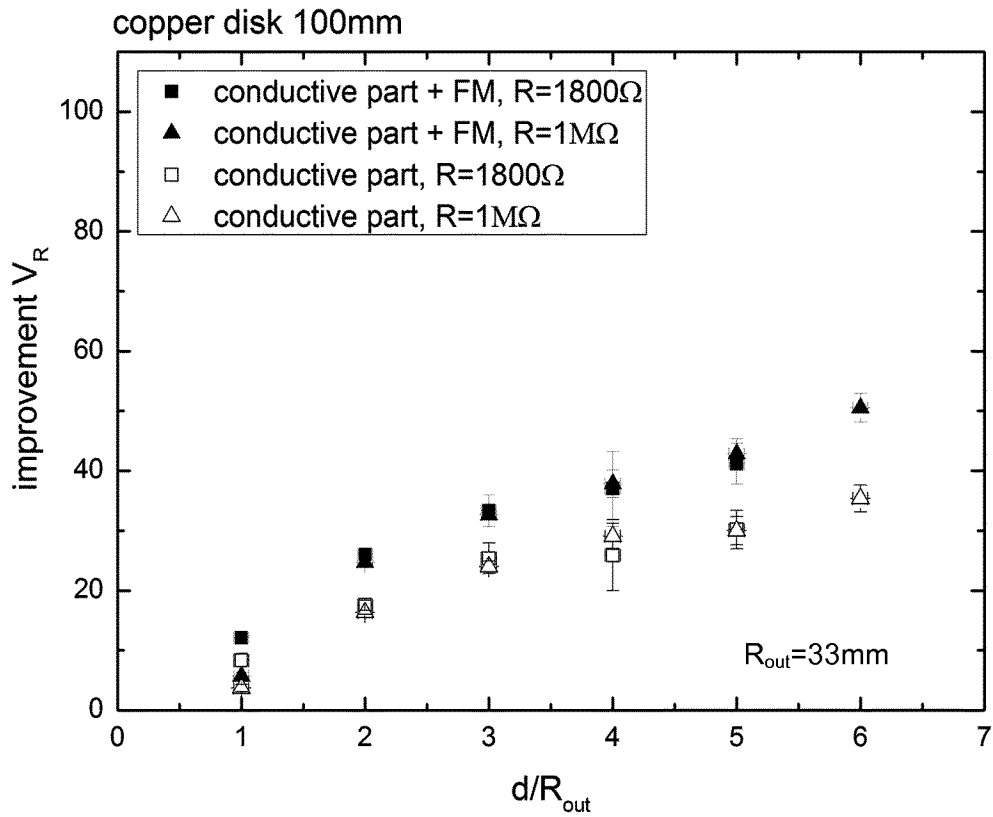


Fig. 10

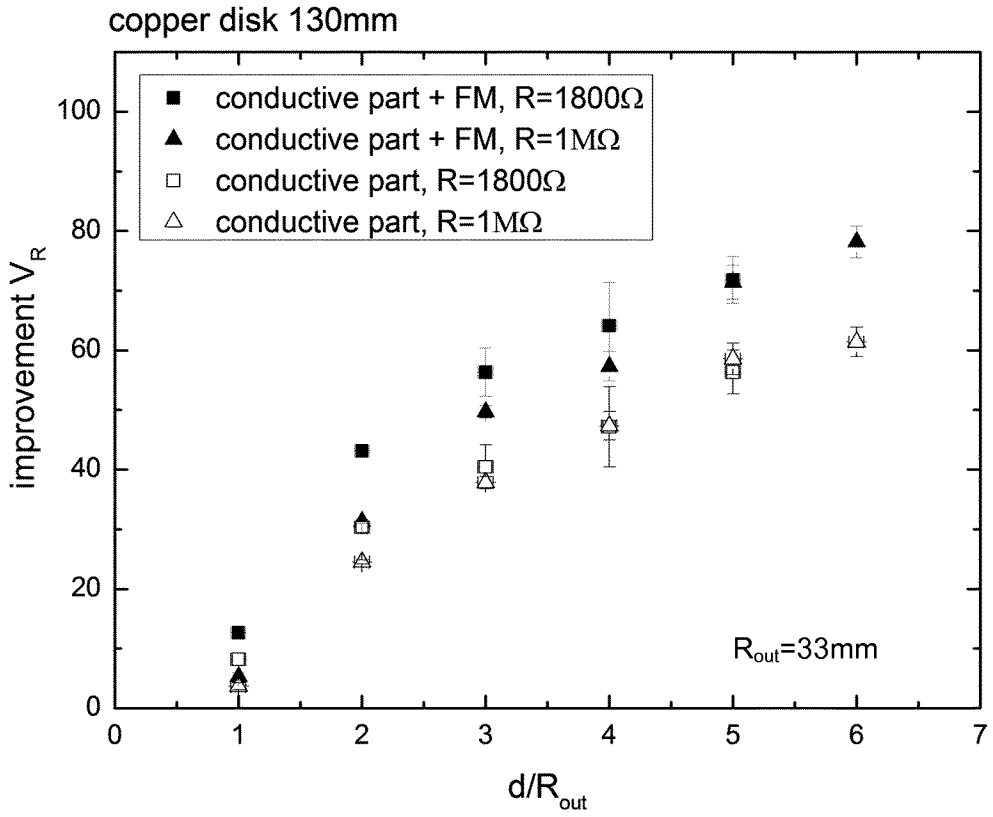


Fig. 11

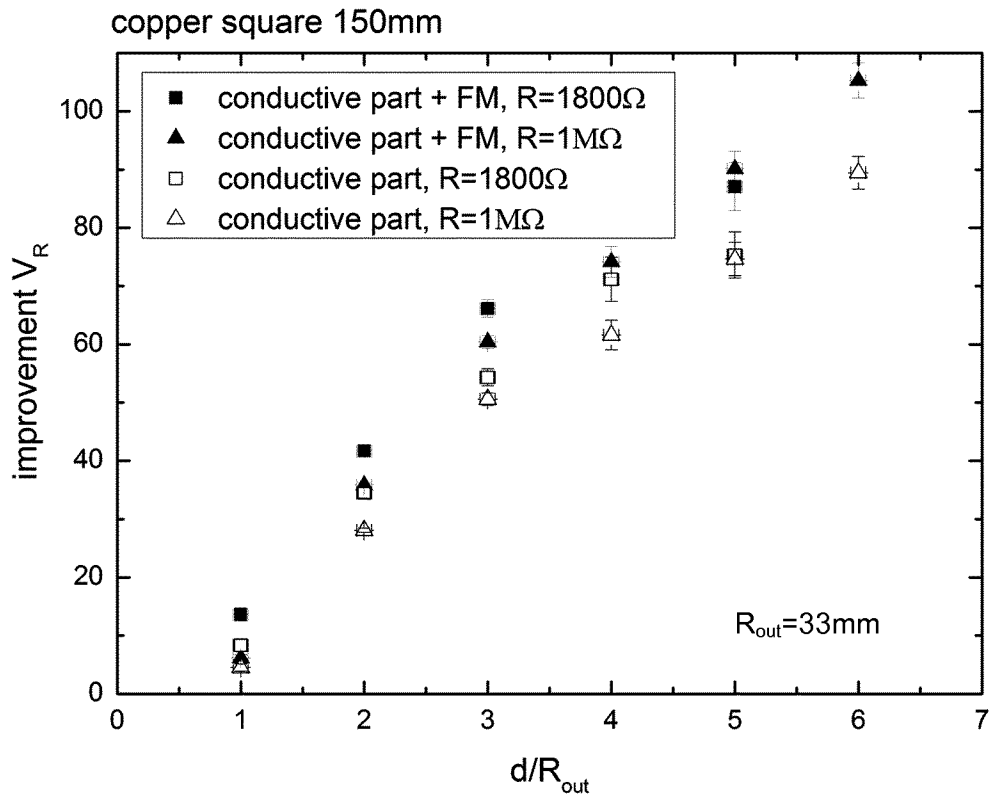


Fig. 12

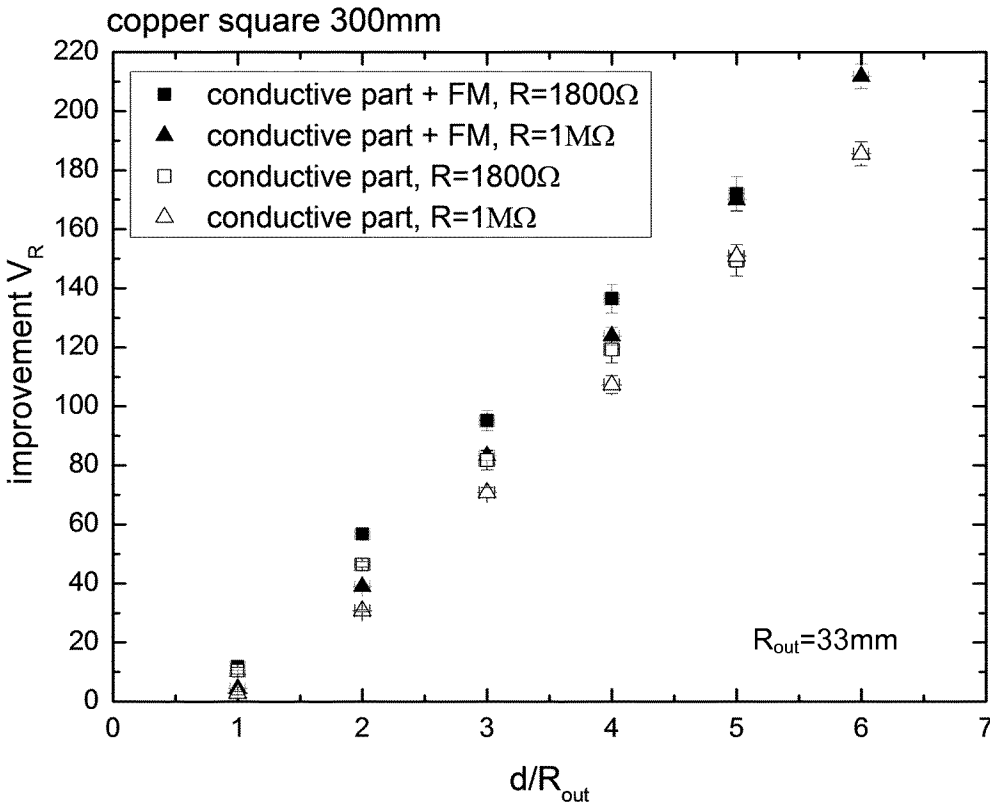


Fig. 13

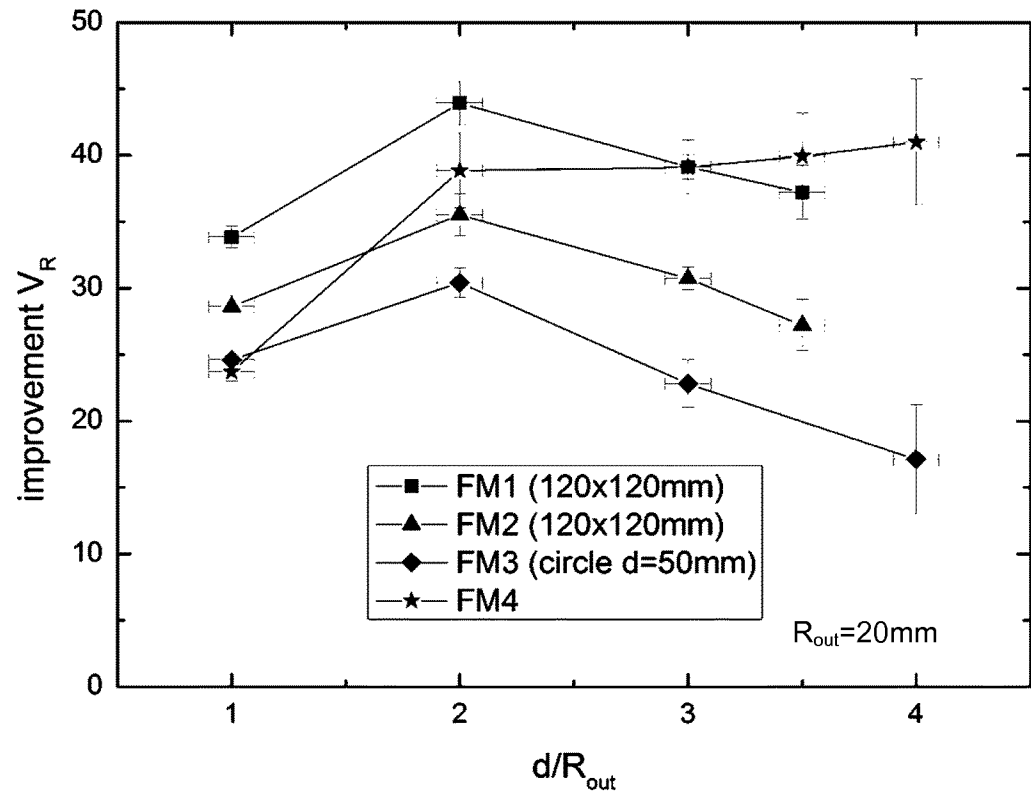


Fig. 14

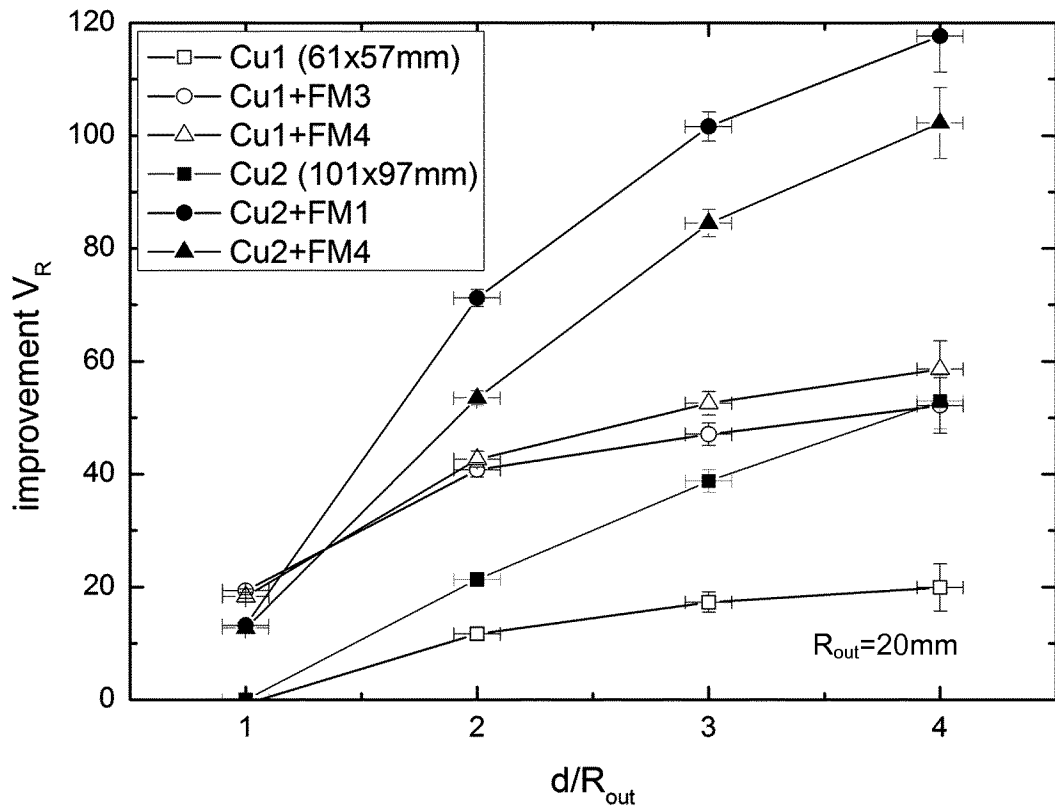


Fig. 15

13/16

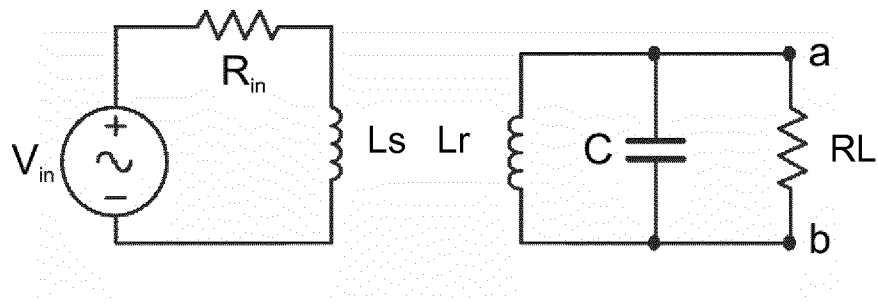


Fig. 16

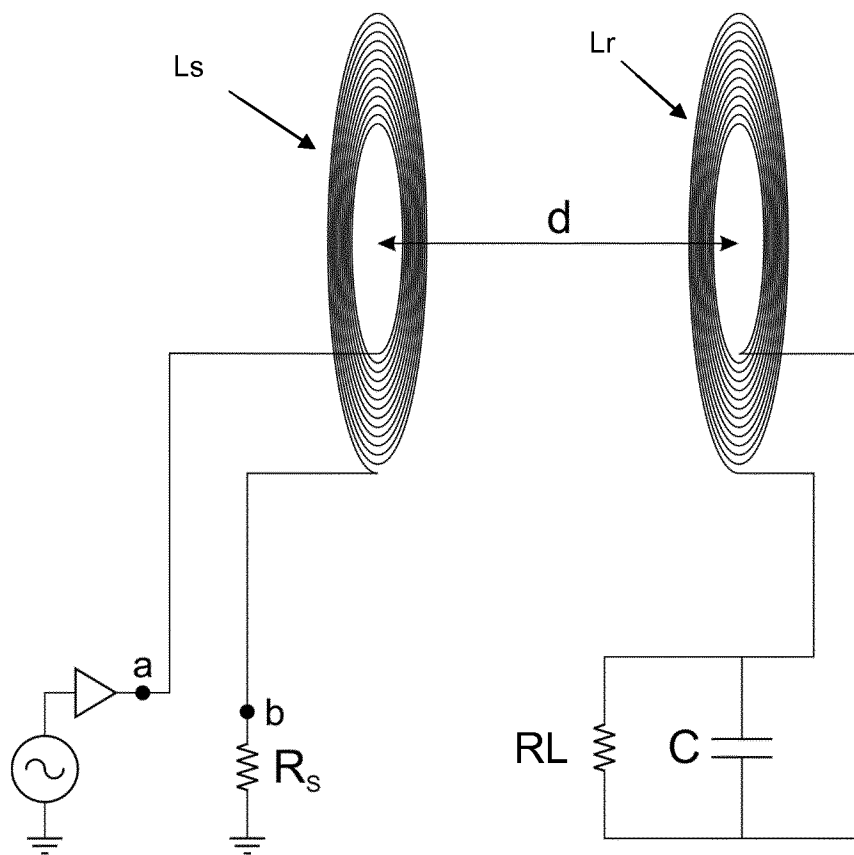


Fig. 17

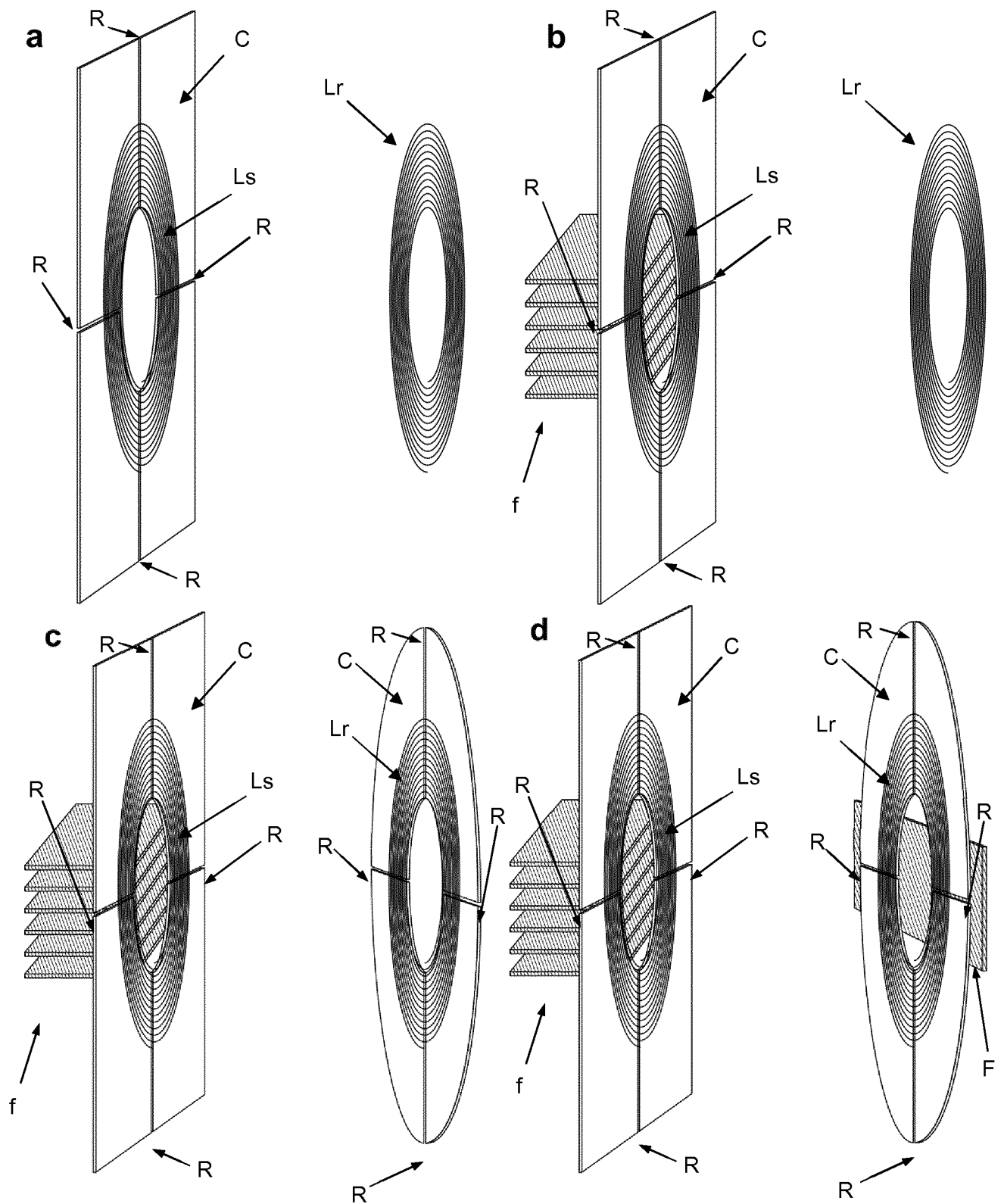


Fig. 18

15/16

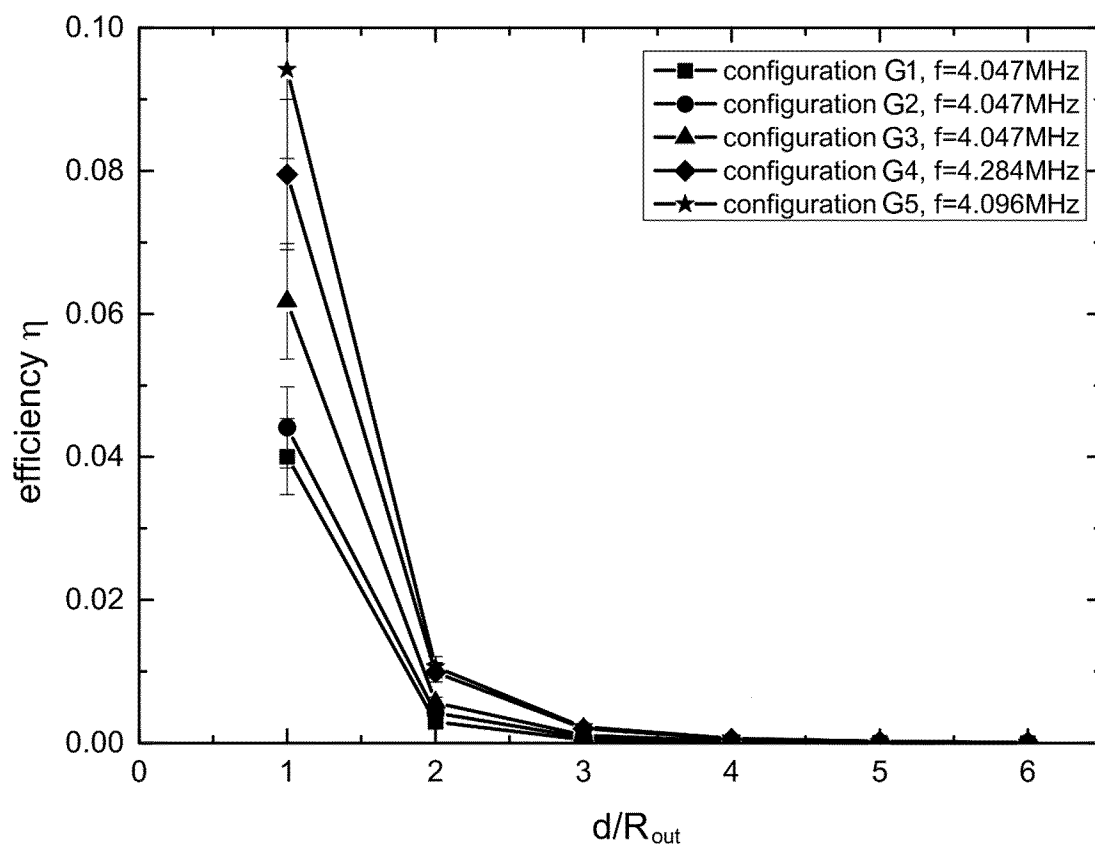


Fig. 19a

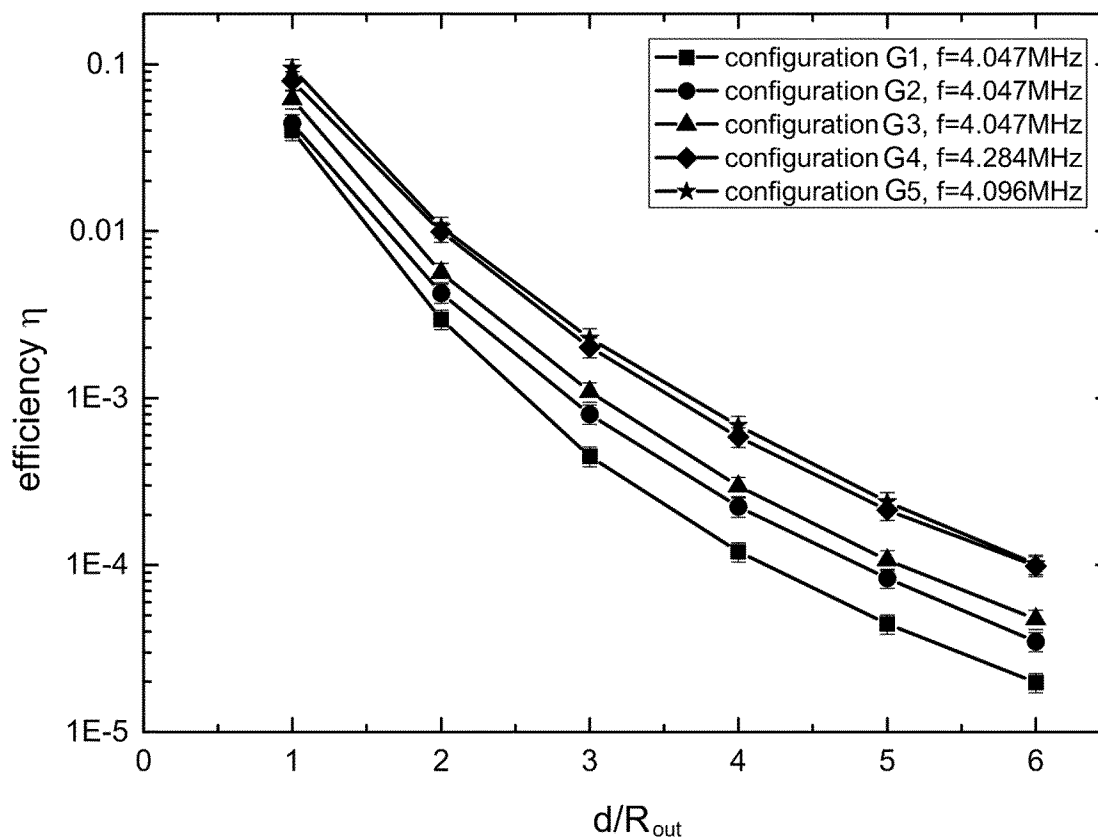


Fig. 19b

16/16

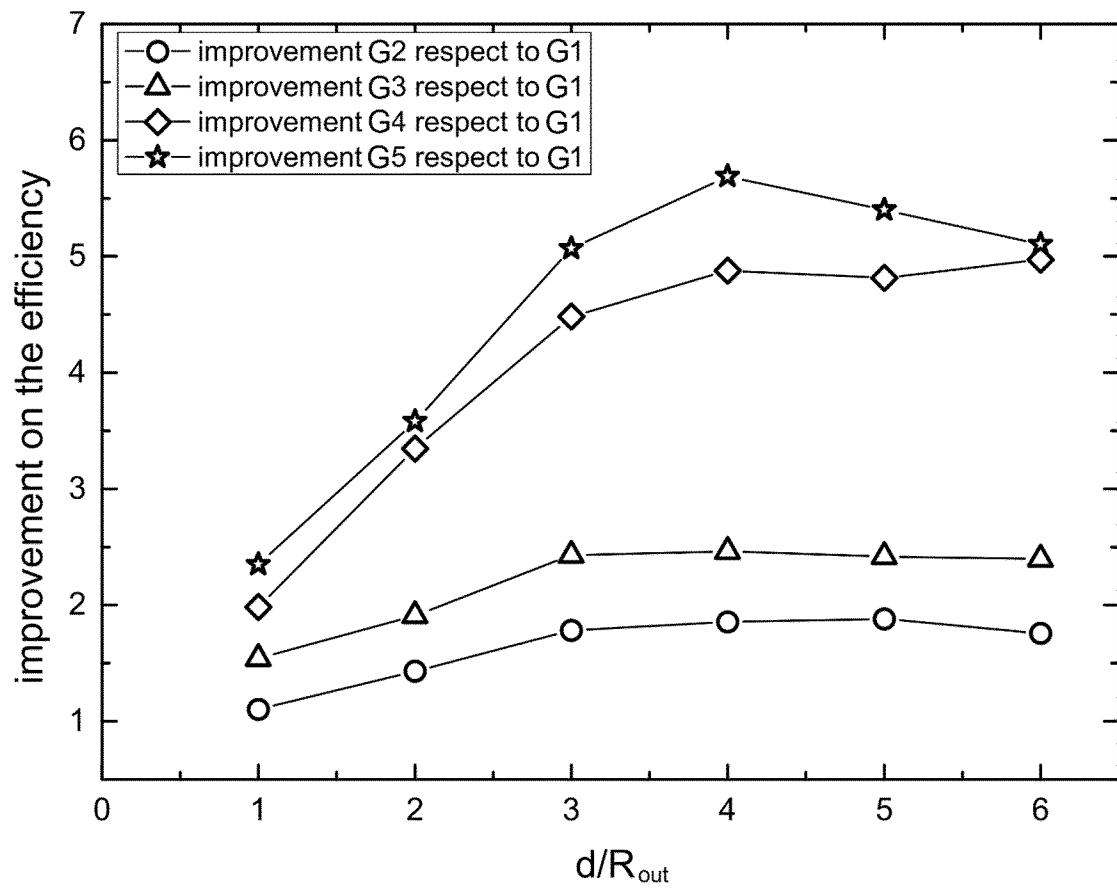


Fig. 20

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/065865

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R33/00
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)
H01F G01R H02J H01Q B60L

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2014/016073 A1 (UNIV BARCELONA AUTONOMA [ES]; SANCHEZ MORENO ALVAR [ES]; NAVAU ROS CAR) 30 January 2014 (2014-01-30) page 1, lines 6 - 9 page 2, lines 11 - 14 page 3, lines 11 - 16 page 6, lines 7, 10 page 9, lines 27 - 33 page 11, line 35 - page 12, line 7 figures 1-13	1-24
A	US 2014/159479 A1 (NOMURA TSUYOSHI [US] ET AL) 12 June 2014 (2014-06-12) paragraphs [0004] - [0008], [0031] - [0034]	1,2, 21-23



Further documents are listed in the continuation of Box C.



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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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"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

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

20 November 2015

Date of mailing of the international search report

26/11/2015

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2015/065865

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2014016073	A1	30-01-2014	NONE

US 2014159479	A1	12-06-2014	NONE
