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(54) Title: METHOD FOR MANUFACTURING A COMMUNICATION DEVICE TO OPERATE IN NEAR FIELD AND COMMUNICATION DEVICE THEREOF

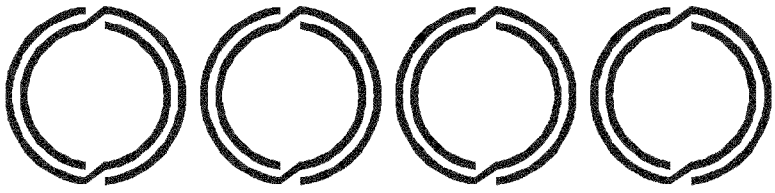


Fig. 2a

(57) Abstract: A method for manufacturing a communication device to operate in near field and communication device thereof In the method said communication device comprises a metamaterial guiding structure and at least onefeed point, the method comprising: exciting the communication device via said at least one feed point with electromagnetic energy; controlling the values of the wavenumber(β) within said metamaterial guiding structure by modifying the metamaterial guiding structure;and calculating imaginary values of the transversal component (ky) of the wavenumber in free space (k), so that the electromagnetic field of the modified metamaterial guiding structure be confined around said metamaterial guiding structure. The communication device is adapted to implement the method of the invention.

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Method for manufacturing a communication device to operate in near field and communication device thereof

Field of the art

The present invention generally relates to electric and/or magnetic field control, and more particularly to a method for manufacturing a communication device to operate in near field and communication device thereof. One of the most straightforward applications of this invention is in the UHF-RFID and microwave RFID technology.

Background of the invention

Radio Frequency Identification (RFID) is the technology that uses electromagnetic waves for non-contact automatic identification of people, animals and objects being prevalent in business, personal, and other applications, and as a result the technology for such communication devices continues to advance in various areas. There are different standards operating at different frequencies. LF-RFID and HF-RFID (125 KHz and 13.56 MHz, respectively) are used in short distance applications. UHF-RFID (840-960MHz) and microwave RFID (2.45MHz and 5.8MHz) are used in applications where great read range of detection is required. Generally, an RFID system consists of two types of elements: Tags and readers. Tags generally will have two components: an antenna and a chip. The antenna performs the tasks of transmission and reception of the electromagnetic waves, while the chip stores the identification code and manages all communication with the reader. Active tags are commonly used in microwave RFID while in UHF-RFID most of the tags are purely passive. For this reason UHF-RFID is preferred in retail and logistics applications since the cost of the tag does not increase significantly the cost of the tagged product. Readers or interrogators are RF transmitting and receiving devices used to communicate with an RFID tag. These readers must include a device to transform the RFID electrical signals in RF Electromagnetic power. For long detection distance (UHF-RFID or microwave RFID) this device is an RF antenna (far field reader) while for small reading distance this device generates some distribution of magnetic or electric field only in the surrounding area of the reader (near field reader).

On another hand, one of the problems at present with the introduction of RFID technology in the retail and the public access is found in the difficulty of simultaneously offer the possibility of controlling items payment in stores and inventory of elements

present in the store. The reason for this difficulty is found in the inability of the UHF-RFID readers (UHF band is suitable for long detection distance and low cost tags) to confine the RF Electromagnetic power in a controlled space. A near field reader is needed in the payment point while a far field reader is needed for inventory purposes. Far field readers based on antennas are very suitable for carrying inventory without having to approach to the product, so that a complete inventory of every store can be made within seconds. Because these devices present high levels of radiation gain, the decay of the field towards the distance is difficult to control. For this reason these devices are not appropriate for payment applications since the definition of a clear coverage zone is not possible and it is impossible to ensure that only the products of a single customer are accounted.

Some solutions incorporating current loops are used in UHF-RFID near field applications. With these types of devices it is difficult to achieve a good compromise between low radiation gain and a large near field coverage. This is due to the fact that the radiation gain of a current loop increases strongly with its radius and also the distance where the near field is present is always of the same order of the size of the loop. Finally, to achieve a proper coverage zone the size of the antenna is always of the order of the wavelength of the UHF-RFID signal in free space, giving rise to excessive values of radiation gain. An example of this technique is the so-called segmented loop, which presents reasonable coverage area but with excessive levels of radiation gain. Some solutions based on segmented loops are used in near field applications, but the use of special tags sensible only to the magnetic field is mandatory. This solution imposes the use of different tags for near field and far field applications since tags sensible to magnetic field only are not compatible with far field RFID readers, since the magnetic field level generated at certain distance from the reader (subjected to power regulation) is not enough to activate these types of tags.

Solutions based on electric coupling between the RFID tag and readers are also known, but as well as in the magnetic case the coverage area is very small for small radiation gains, since these devices are based on small antennas or resonators whose radiation gain increases dramatically with dimensions.

Summary of the Invention

This invention overcomes the aforementioned problems by providing a new strategy which is based on the replacement of communication devices that transforms

the electrical RFID signals of the reader in RF Electromagnetic power with near-field communication devices sensitive to magnetic as well as to the electric field and that work under an evanescent solution so that there is an exponential decay of the field versus distance and therefore do not give rise to significant components of radiated field but allowing an arbitrary near field coverage zone. As a result the proposed strategy avoids giving rise to multiple and undesired readings at different points.

This kind of evanescent solutions or surface waves are known in natural environments, but these media do not have the ability to sufficiently control as to impose confinement levels suitable for the application proposed in this invention. Furthermore, this mode of operation based on surface waves has been used in the design of antennas but through the introduction of discontinuities or by the excitation of arrays of radiating elements, as surface waves by themselves do not have the ability to radiate since they are slow wave solutions.

According to a first aspect, the invention provides a method for manufacturing a communication device to operate in near field, wherein said communication device comprises, as commonly in the field, a metamaterial guiding structure and at least one feed point. On contrary of the known proposals, the proposed method comprises exciting the communication device, for instance an RFID device, via said feed point with electromagnetic energy; controlling the values of the wavenumber β within said metamaterial guiding structure by modifying the metamaterial guiding structure; and calculating imaginary values of the transversal component (k_y) of the wavenumber in free space (k), so that the electromagnetic field in the vertical direction of the modified metamaterial guiding structure be confined around said metamaterial guiding structure in a controllable fashion.

Moreover, since the RF signal is confined around the device, the dimensions of the structure can be made arbitrarily large by means of increasing the number of unit cells. This will increase the coverage volume without increasing the radiation gain.

The values of wavenumber β can be controlled in an embodiment by adjusting the effective dielectric permittivity (ε) and the magnetic permeability (μ) of the metamaterial guiding structure. On another hand, according to another embodiment, said (β) values can be controlled by means of other dispersive structures with a known dispersion relation such as an Electromagnetic Band Gap, structures generating magneto-inductive waves or electro-inductive waves or a periodic structure.

The modification of the metamaterial guiding structure can also include a calculation of the dimensions of a unitary cell of the metamaterial guiding structure.

Preferably, the metamaterial guiding structure will be implemented by a planar technology, a Substrate Integrated Waveguide (SIW) technology, a waveguide technology, or any other similar technology.

The calculated imaginary values of the transversal component (k_y) comprises obtaining values of wavenumber β higher than values of the wavenumber *k*.

According to some embodiments, the metamaterial structure can consist, as a preferred implementation, of several unit cells each one comprised by two concentric metallic rings with slits etched in each ring at opposite sides and a transmission line implemented in a planar substrate, wherein said two concentric metallic rings comprises non-Byanisotropic Split Ring Resonators and said transmission line comprises a slot line where metal connections are inserted between slots. Alternatively, the metamaterial structure can also consist of several unit cells, each one comprised by a combination of lumped or semi-lumped reactances in series configuration controlling the effective permeability and by a combination of lumped or semi-lumped reactances in shunt configuration controlling the dielectric permittivity.

According to a second aspect the invention provides a communication device, such as an RFID device or any other device tacking advantage of the spatial field confinement, to operate in near field, comprising a metamaterial guiding structure comprising several unit cells and at least one feed point to be excited. On contrary to the known proposals, said metamaterial guiding structure M, consisting of several unit cells, is modified in order to control the values of the wavenumber β within said metamaterial guiding structure M according to the method of claim 1.

According to a preferred embodiment, each one of said several unit cells can include two concentric metallic rings with slits etched in each ring at opposite sides and a transmission line implemented in a planar substrate, wherein said two concentric metallic rings comprises non-Byanisotropic Split Ring Resonators and said transmission line comprises a slot line where metal connections are inserted between slots. Preferably, said non-Byanisotropic Split Ring Resonators and said slot line are assembled in superposition each one in a side of said planar substrate.

Alternatively, in another embodiment, each one of said several unit cells can include lumped or semi-lumped reactances arranged in series configuration and lumped or semi-lumped reactances arranged in shunt configuration.

According to some embodiments, the metamaterial guiding structure can be arranged according to a one-dimensional, bi-dimensional or three-dimensional arrangement describing one of: a linear path, a circular path, a polygonal path, an

irregular path, a square periodic lattice, a rectangular lattice, a hexagonal lattice, a periodic lattice, an irregular lattice, or fractal geometry.

Moreover, according to a perfection of the invention, alternatively the metamaterial guiding structure can contain some other lumped or semi lumped resonators, for instance the resonators of Fig. 4 or dielectric resonators, instead of the two concentric metallic rings. Another possibility can be, for instance, having a complementary resonator such as a slot in a metallic sheet describing the shape of any of the resonator of Fig. 4.

Finally, in yet another embodiment, the metamaterial guiding structure can have a plurality of said feed points.

Brief Description of the Drawings

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

Fig. 1 illustrates the behavior followed by the proposed structure M according to the first aspect of the invention.

Figs. 2a, 2b and 2c are an example of the proposed communication device implemented by means of a combination of Non-Byanisotropic Split Ring Resonators and slot line with metal connections inserted in the slot (Fig. 2c) according to a preferred embodiment of the invention. Fig. 2a shows the layer that contains the Non-Byanisotropic Split Ring Resonators and Fig 2b the layer that contains the transmission line slot line.

Fig. 3 is an illustration of the dispersion relation diagram obtained from the analysis of the electromagnetic structure of Figs. 2a, 2b and 2c.

Fig. 4 is an example of the topologies corresponding to (a) the Non-Byanisotropic Split Ring Resonator (NBSRR), (b) the Double-slit Split Ring Resonator (D SRR), (c) the Spiral Resonator (SR), (d) the Double Spiral Resonator (DSR) and (e) the Split Ring resonator (SRR) according to some embodiments of the invention. The equivalent circuits for these topologies are depicted in the right column.

Fig. 5 is an example of the proposed communication device wherein the unit cells of the metamaterial structure M is disposed describing a circular path, according to an embodiment of the invention.

Description of Several Embodiments

The principle of operation of the invention is based on the implementation of near-field communication devices, such as RFID devices, based on artificial electromagnetic guiding structures called metamaterials M. Generally, these types of artificial media can control the wavenumber of the signal that travels through them so that these control can be used for confining the electromagnetic field around the structure M. Fig. 1 illustrates the behavior of the proposed metamaterial structure M according to the first aspect of the invention.

In reference to Fig. 1, where β corresponds to the wavenumber of the signal traveling through the metamaterial structure M, k corresponds to the wavenumber of the signal propagating in air (signal induced by the metamaterial structure into the air) and k_x and k_y correspond to the projection of the longitudinal and transverse components of the vector k on the surface of the metamaterial structure M. As a characteristic of the invention, the wavenumber β can be adjusted appropriately by designing the metamaterial structure M either by modifying the metamaterial guiding structure adjusting the effective dielectric permittivity (ε) and the magnetic permeability (μ) of the metamaterial structure or by means of other dispersive structures (i.e. an Electromagnetic Band Gap, structures generating magneto-inductive waves or electro-capacitive waves or a periodic structure).

The magnitude of the vector k will depend solely on the environment surrounding the metamaterial structure M, in this case the air, and can therefore be calculated as ω / c, where ω is the angular frequency of the signal and c the light speed in the air. On the other hand, to ensure compliance with the relations of continuity on the interface between the metamaterial structure M and the surrounding environment is necessary that the vector β matches with k_x. In this way it can be obtained

$$k^2 = k_x^2 + k_y^2 = \beta^2 + k_y^2$$

wherein by isolating k_y

$$k_y = \pm\sqrt{k^2 - \beta^2}$$

So by properly controlling or adjusting the value of β there are obtained real and imaginary values of the k_y parameter. This result will depend on the sign of the above square root (the sign of k^2-β^2). Recalling the general solution of the two-dimensional plane wave propagation in free space it is obtained that the spatial term of the solution contains:

$$e^{-j\vec{k}\cdot\vec{r}} = e^{-jk_x x} e^{-jk_y y}$$

The real values of k_y lead to the so-called progressive (or leaky) wave antennas (radiative solutions) under which the value of β can control the emission direction of the antenna. For instance, given that the magnitude of the vector k is fixed, a value of $\beta = 0$ implies that $k = k_y$ and therefore the radiation in this case is completely vertical (or broadside) (Fig. 1). On another hand, $\beta=k$ implies $k_y =0$ therefore radiation occurs in the propagation direction of the signal within the metamaterial structure M.

The proposed method, in a characteristic manner, makes use of this flexibility for controlling the propagation characteristics in order to impose values β leading to imaginary values of k_y and thus avoiding the radiation but allowing the control of the distribution of electric and magnetic fields around the metamaterial structure M. By designing the metamaterial structure M in order to get imaginary values of the k_y ($\beta^2>k^2$) it is obtained

$$e^{-j\vec{k}\cdot\vec{r}} = e^{-jk_x x} e^{-\alpha y}$$

where α is a positive real number. That supposes an exponentially decrease of the electric and magnetic fields as it is moved away from the surface of the metamaterial structure M (in the y direction). Since the value of β can be adjusted in the design stage of the metamaterial structure M, it is possible to impose the level of confinement of the electromagnetic field around the structure, ensuring that near the communication device (or reader) the field would be large enough to provide a good read but in no case can lead to undesired readings in reading adjacent communication devices. Since the obtained device does not radiate, the dimensions of the structure can be done arbitrarily large (increasing the number of unit cells) to increase the coverage area.

Referring now to Figs. 2a, 2b and 2c, it is illustrated a preferred embodiment of the invention, in this case, the metamaterial structure M consists of two levels of metallization. One of them contains a transmission line (slot line) intercalating metal connections between the slots (Fig. 2b). The other layer contains rings Non Byanisotropic Split Ring Resonator (NBSRRs) on the upper face (Fig. 2a). In this structure M the connections between the slots can adjust the value of the effective dielectric permittivity (ε) while the split ring resonator adjusts the value of the effective magnetic permeability (μ). The control of both magnitudes, in this structure can achieve both positive and negative values, can force the required value of the wavenumber β wished to obtain the proper value of α for the proposed application.

Figure 3 shows the result of the dispersion relation diagram βl (bold line) depending on the frequency, where l is the length of a unit cell of the periodic metamaterial structure M) obtained from the analysis of the electromagnetic structure

of Figs. 2a and 2b. Given the size of a unit cell (31.7mm) and considering, for instance, the UHF RFID central frequency (867MHz), values of magnitude of βl greater than 33 ° give rise to an evanescent wave in the vertical direction (*y* direction of Fig. 1). In this case, at the interest frequency it is observed a value of 51.1 ° that would lead to a value of α = 0.022 [1/mm] (thin line) which supposes an attenuation distance (1/α) of 46.5 mm, for a frequency of 867MHz. The regions where βl shows negative slope with frequency correspond to negative values of β. Adjusting the dimensions of each unit cell said scatter diagram can be conveniently modified, allowing to design the device with $\beta>0$ or with $\beta<0$.

By using the slot line transmission line the entire metamaterial structure M constructively contributes to the formation of electric and magnetic fields and avoids the cancellation of currents (which causes field cancelation) that occurs, for instance, in a coplanar line. Moreover, the use of this planar technology can bring to market the resulting designs quickly and at a low cost, since the resulting structures are fully compatible with standard manufacturing processes of printed circuit boards (PCB).

As explained before, β value can be adjusted, in an alternative, by means of a dispersive structure. For this case, where an infinite line is composed of a cascade of identical two-port networks (unit cells). Each cell can be characterized by its ABCD matrix, where

$$\begin{bmatrix} V_n \\ I_n \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_{n+1} \\ I_{n+1} \end{bmatrix}$$

so it can be proven that the propagation constant $\gamma = \alpha + j\beta$ of the whole network is related to the ABCD matrix of the single unit cell according to the next expression:

$$\cosh \gamma l = \frac{A + D}{2}$$

wherein for the case of non-attenuating waves ($\alpha = 0,\ \beta \neq 0$) the previous expression becomes:

$$\cos \beta l = \frac{A + D}{2}$$

then controlling the relation between the current and voltages at the input and output of a single unit cell it can be controlled the dispersion relation of the whole periodic structure.

Referring to Fig. 4, there are shown some other possible embodiments of the invention. For instance, the metamaterial structure M can consists of several unit cells, each one comprised either by a combination of lumped or semi-lumped reactances in series configuration controlling the effective permeability and by a combination of

lumped or semi-lumped reactances in shunt configuration controlling the dielectric permittivity. These reactances can be implemented by means of lumped or semi lumped elements, metallic strips or slots combined with dielectrics or by means of the resonators of Fig. 4.

Moreover, the metamaterial guiding structure can be arranged according to a one-dimensional, bi-dimensional or three-dimensional arrangement describing for instance a linear path, a circular path (Fig. 5), a polygonal path, an irregular path, a square periodic lattice, a rectangular lattice, a hexagonal lattice, a periodic lattice, an irregular lattice, or fractal geometry, with arbitrary number of cells in order to adjust the coverage area.

The scope of the present invention is defined by the attached set of claims.

Claims

1. A method for manufacturing a communication device to operate in near field, wherein said communication device comprises a metamaterial guiding structure and at least one feed point, **characterized in that** the method comprises:

a) exciting the communication device via said at least one feed point with electromagnetic energy;

b) controlling the values of the wavenumber β within said metamaterial guiding structure by modifying the metamaterial guiding structure; and

c) calculating imaginary values of the transversal component (k_y) of the wavenumber in free space (k), so that the electromagnetic field of the modified metamaterial guiding structure be confined around said metamaterial guiding structure.

2. A method according to claim 1, wherein said values of wavenumber β are controlled by adjusting the effective dielectric permittivity (ε) and the magnetic permeability (μ) of the metamaterial guiding structure.

3. A method according to claim 1, wherein said values of wavenumber β are controlled by means of a dispersive structure, said dispersive structure comprising an Electromagnetic Band Gap, structures generating magneto-inductive waves or electro-inductive waves or a periodic structure.

4. A method according to previous claims, wherein the modification of the metamaterial guiding structure further comprises calculating the dimensions of a unitary cell of said metamaterial guiding structure.

5. A method according to claim 1, wherein said calculated imaginary values of the transversal component (k_y) comprises obtaining values of magnitude of wavenumber β higher than the wavenumber k values.

6. A method according to any of claims 1 to 3, wherein said metamaterial guiding structure comprises several unit cells, each one comprised by two concentric metallic rings with slits etched in each ring at opposite sides and a transmission line implemented in a planar substrate, wherein said two concentric metallic rings comprises non-Byanisotropic Split Ring Resonators and said transmission line comprises a slot line where metal connections are inserted between slots.

7. A method according to claims 1 or 2, wherein said metamaterial guiding structure comprises several unit cells, each one comprised by a combination of lumped or semi-lumped reactances in series configuration controlling the effective permeability and by a combination of lumped or semi-lumped reactances in shunt configuration controlling the dielectric permittivity.

8. A method according to previous claims, comprising implementing said metamaterial guiding structure by a SIW technology, a waveguide technology or a planar technology.

9. A method according to previous claims, wherein said communication device to operate in near field comprises a RFID device.

10. A communication device to operate in near field, comprising a metamaterial guiding structure M comprising several unit cells and at least one feed point to be excited, **characterized in that** said metamaterial guiding structure M, consisting of several unit cells, is modified in order to control the values of the wavenumber β within said metamaterial guiding structure M according to the method of claim 1.

11. A communication device according to claim 10, wherein each one of said several unit cells comprises two concentric metallic rings with slits etched in each ring at opposite sides and a transmission line implemented in a planar substrate, wherein said two concentric metallic rings comprises non-Byanisotropic Split Ring Resonators and said transmission line comprises a slot line where metal connections are inserted between slots.

12. A communication device according to claim 10, wherein each one of said several unit cells comprises lumped or semi-lumped reactances arranged in series configuration and lumped or semi-lumped reactances arranged in shunt configuration.

13. A communication device according to claim 11, wherein said non-Byanisotropic Split Ring Resonators and said slot line are assembled in superposition each one in a side of said planar substrate.

14. A communication device according to claim 10, wherein said metamaterial guiding structure M is arranged according to a one-dimensional, bi-dimensional or three-dimensional arrangement describing one of: a linear path, a circular path, a polygonal path, an irregular path, a square periodic lattice, a rectangular lattice, a hexagonal lattice, a periodic lattice, an irregular lattice, or a fractal geometry.

15. A communication device according to claim 10, wherein said metamaterial guiding structure M comprises a plurality of said feed points.

16. A communication device according to any of previous claims 10 to 15, wherein said communication device is a RFID device.

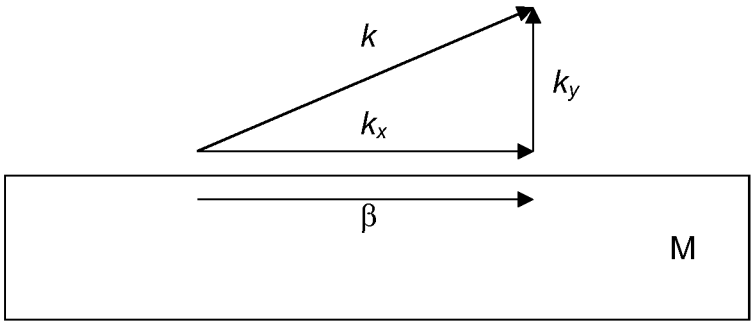


Fig. 1

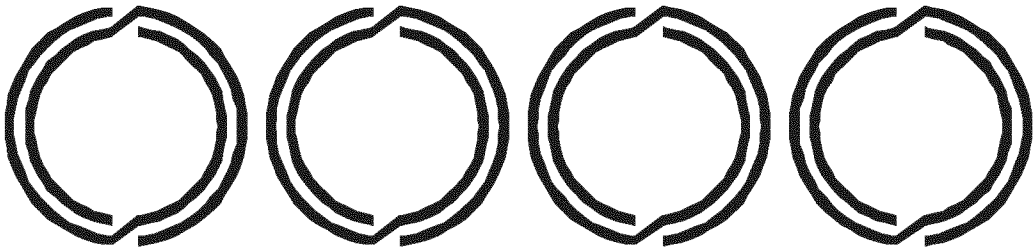


Fig. 2a



Fig. 2b

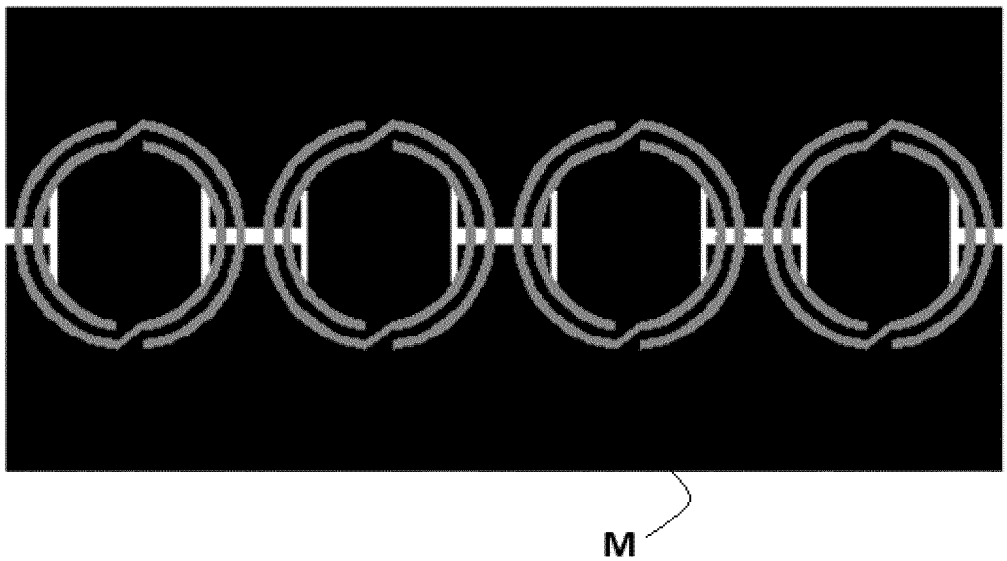

M

Fig. 2c

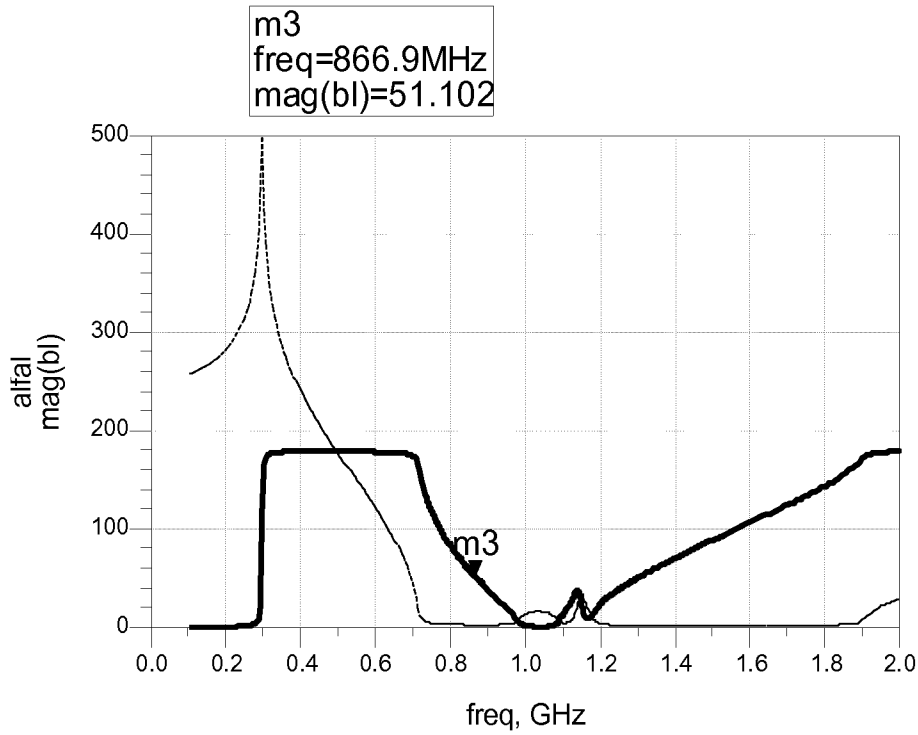

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mag(bl)=51.102
alfal
mag(bl)
500
400
300
200
100
0
m3
0.0
0.2
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0.8
1.0
1.2
1.4
1.6
1.8
2.0
freq, GHz

Fig. 3

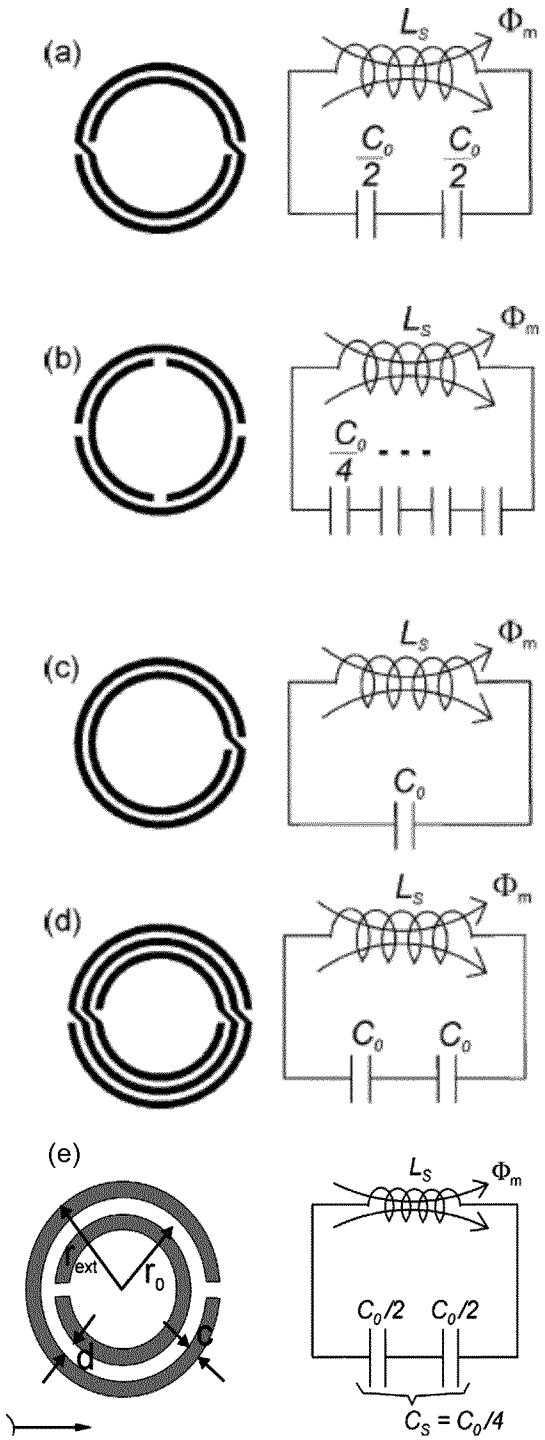

(a)
L_s
Φ_m
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(b)
L_s
Φ_m
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(c)
L_s
Φ_m
C_0
(d)
L_s
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Fig. 4

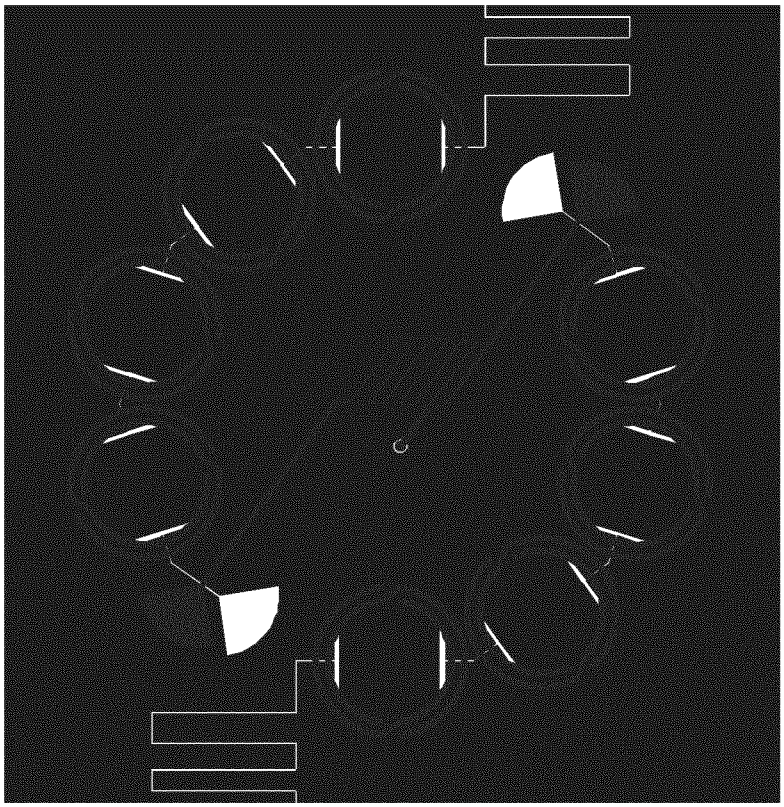


Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/064806

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06K19/077 H01P1/20 H01Q15/00
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)
G06K H01P H01Q

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2010/053013 A1 (KONISHI TAKAYOSHI [JP] ET AL) 4 March 2010 (2010-03-04) paragraphs [0059] - [0068]	1-16
X	EP 2 560 132 A1 (HAND HELD PROD INC [US]) 20 February 2013 (2013-02-20) paragraphs [0026] - [0042]	1-16
X	US 2009/284351 A1 (ROSSMAN COURT [US] ET AL) 19 November 2009 (2009-11-19) paragraphs [0051] - [0053]	1-16

☐ 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	Date of mailing of the international search report
28 October 2014	05/11/2014

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

Information on patent family members

International application No
PCT/EP2014/064806

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2010053013 A1	04-03-2010	JP 5271714 B2	21-08-2013
		US 2010053013 A1	04-03-2010
		WO 2008062562 A1	29-05-2008
EP 2560132 A1	20-02-2013	CN 103106375 A	15-05-2013
		EP 2560132 A1	20-02-2013
		US 2013043309 A1	21-02-2013
US 2009284351 A1	19-11-2009	NONE	