Modeling, Simulation and Practical Realization of the Spiral Inductors Used in Wireless Power Systems

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***Abstract* - With the increase of the number of devices powered and using wireless systems, the optimal design of such systems is necessary. The present study aims at determining the influence of parameters like distance between inductors and the placement of ferrite layers on the phenomena regarding the spiral inductors through their numerical modelling. A simple wireless power system constructed from an emitter and a receiver spiral inductor is considered in the present study. The numerical modelling of the system is made using the software program Ansys Maxwell 3D Field Simulator. Also, a comparison of the results obtained from the modelling and simulation of this wireless power system and from a practical model made in the laboratory is presented. As the modelled structure, the practical model is constructed from two spiral inductors. The importance of numerical modelling of the structure in order to determine an optimum is highlighted. The parameters obtained and analysed from the 3D model are magnetic field intensity, magnetic induction and mutual inductance, while for the constructed model the voltage is studied. For the modelled structure, the distance between the receiver and the emitter is varied between 0.05 mm and 5 mm, considering the structures with and without the ferrite layers in order to reach a conclusion.**

Cuvinte cheie: *bobină spirală, receptor, emiţător, ferită, parametri specifici.*

Keywords: *spiral inductor, receiver, emitter, ferrite, specific parameters.*

I. Introduction

Transmissions are made through wires or wireless as we all know, but a main disadvantage for the wire method is the energy loss during the transmission. This is one of the main reasons why wireless transmission is highly used nowadays. Wireless Power Transmission (WTP) can be used for short and long distances transmissions and it is faster than the wire transmission method.

A major advantage of WTP is the maintenance cost, which is lower. WTP has a high demand on the electronics market and it is quickly implemented in fields like defense industry or medical care. WTP is also implemented in solar based satellites and for power supplying airplanes, electrical vehicles, robots and other electric/electronic devices [1], [2].

The WTP technology was easily accepted at a global level. Some countries like the USA invest for the implementation of this technology to have the maximum use of the network systems power and to reduce the cost of cable installation. This technology is still in early stages, fact which is a huge opportunity for the new developers to enter the market [1], [2].

For now the wireless energy transport market is concentrated on the contactless charge technologies for the Li-ion batteries development, batteries massively used for the consumer electronics and electric vehicles. There is a high probability that long term development in the industry will concentrate on contactless supply of the electronic devices (consumer products, industrial or for military use) will become more available on a large scale [1], [2], [3].

A wireless power system involves a transfer of energy between two or more objects through an electromagnetic field, as shown in Fig. 1 [1]. The technology requires two inductors: an emitter and a receiver, and the emitter inductor generates a magnetic field. The emitter's magnetic field induces a voltage in the receiver inductor, which can then be used to power a mobile device or charge a battery.

The wireless charge is based on one of the simplest effects of the variable electromagnetic field, namely that in time a variable electromagnetic field induces an electric current in a circuit in its vicinity.

The most popular wireless charging standards are: Qi-Wireless Power Consortium developed, Rezence-the Alliance for Wireless Power developed, PMA-developed by Power Matters Alliance [3]. It must be mentioned that not all wireless charged devices can be charged at any platform, because they must comply with the same standard. Fortunately, devices can comply with more than one standard [5].

II. Model Implementation

At the base of this study is a practical model made in the laboratory constructed from two spiral inductors: an emitter and a receiver as it can be observed in Fig. 2b along with a suggestive representation of the phenomenon (Fig. 2a) [4].

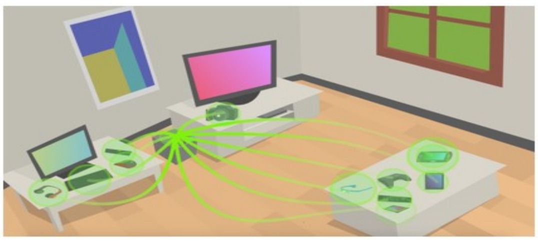
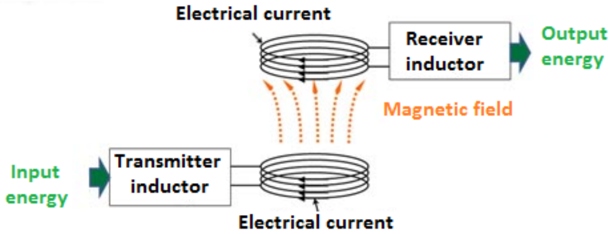


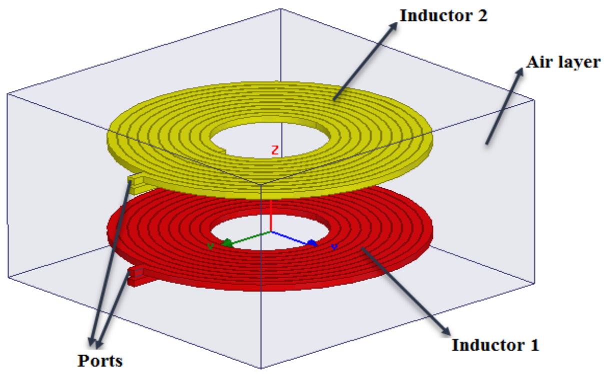
Fig. 1. Wireless power system [1].

For this study, the wireless power system was modelled and simulated with the help of the software program ANSYS Maxwell 3D Field Simulator. Three cases were considered, namely the spiral inductors without ferrite, spiral inductors considering the emitter inductor on ferrite and spiral inductors considering both the emitter and the receiver inductors on ferrite as it can be seen in Fig. 3 [7-12].

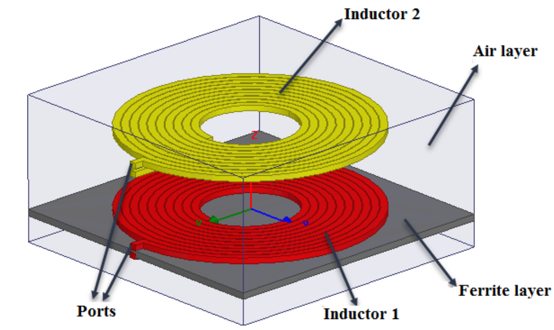


a) General structure of a wireless power system

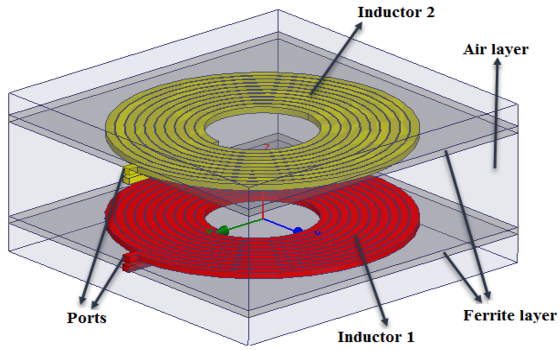
b) Practical model made in the laboratory
Fig. 2. The general structure of a wireless power system.



a) Spiral inductor without a ferrite layer



b) Spiral inductor considering the emitter inductor on a ferrite layer



c) Spiral inductor considering the emitter and receiver inductors on a ferrite layer
Fig. 3. Cases considered for the study.

The wireless power system which constituted the starting point of this research is part of the Qi category, platform which is powered with a 12 V DC voltage. Further, the wireless power systems realized by the authors having the emitter and receiver inductors with and without ferrite are presented [3].

The constructed emitting and receiving conductors are made from copper with a diameter of 0.45 mm, 10 turns. Figure 4 presents the electrical scheme of the first wireless power system proposed for analysis. It can be seen that it contains the two inductors mentioned above, one having the role of emitter, the other having the role of receiver, two MOSFET IRFP 250, two resistors of 120 Ω, two resistors of 12 kΩ, two Zener diodes, two diode UF4007 and a LED through which it is desired to show the voltage in the receiver inductor as it is induced. The emitting inductor is powered with 12 V DC voltage from the source, and the receiver inductor is overlapped over the emitting inductor without any distance between them. It can be seen in Figure 5 that in the receiver inductor a voltage of 1.8 V was induced, sufficient to turn on the LED attached to it. Further, the influence of ferrite on the induced voltage for different configurations is analysed [8], [9], [10], [13].

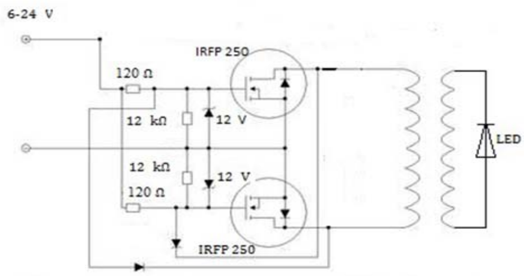


Fig. 4. Electrical scheme of the first power system.

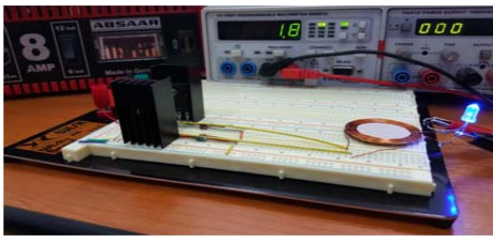


Fig. 5. The measured voltage in the receiver of the wireless system without ferrite.

In the second case, the emitter inductor is located on a ferrite layer. Analysing the results obtained for the second system proposed, it was observed that in the case in which the receiver is overlapped on the emitter, the induced voltage in the receiver is about 2.1 V, as shown in Figure 6.

The third structure considered was the one where both inductors are situated on ferrite layers. The induced voltage in the receiver had a value of 2.3 V [13].

Considering the results obtained it can be observed that the voltage measured in the receiver increased, for the structure having both inductors situated on ferrite layers.

Considering the influence of the distance between the emitting and receiving spiral inductors, the next step consider is the case in which the inductors are not overlapped, but between them there is a distance of 10 mm, respectively 15 mm. The measured voltages for different types of inductors and variations distances are centralized in Table I, and represented in Figure 8. As it can be observed, the value of the induced voltage increases with the decrease of the distance between the spiral inductors. After inserting the ferrite layers, it can be stated that the voltage value increased for the structures with the ferrite layers.

After constructing the model, an idea about the parameter influence can be drawn, but in some cases like the variation of the distance between the spiral inductors, the parameters are hard to be varied due to the small dimensions of the model. Thus, the numerical modelling of the system is the easier way to determine their influence.

Fig. 6. The measured voltage in the receiver inductor for the case in which the emitter inductor, is situated on the ferrite.

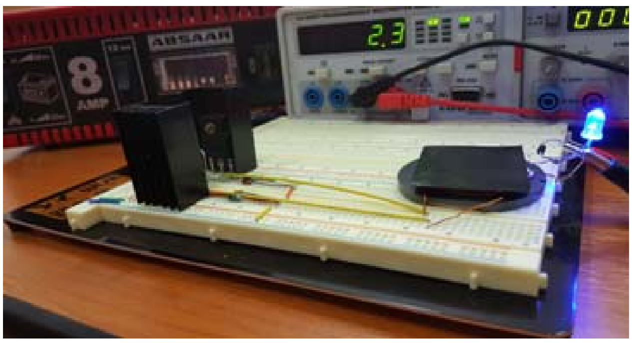


Fig. 7. The measured voltage in the receiver inductor for the case in which both inductors are situated on ferrite.

TABLE I.
COMPARISON OF THE RESULTS OBTAINED

Types of monolayer inductors	Measured Voltage (V) versus Distance (mm)		
	0 mm	10 mm	15 mm
Inductors without ferrite	1.8	1.1	0.7
Emitter inductor with ferrite	2.1	1.5	1.1
Both inductors with ferrite	2.3	1.7	1.3

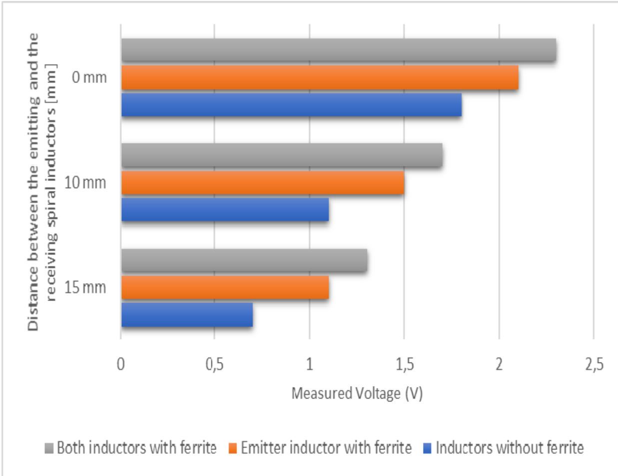


Fig. 8. The measured voltage in the receiver inductor for the three cases considered and at different distances between the inductors.

For the implementation of a wireless power system, studies regarding the optimum inductor configuration are necessary. In order to analyse and identify the effects of a wireless system [6], the starting point was a model of a system made from two monolayer spiral inductors. One inductor was considered to be the emitter and the other the receiver.

The distance between the two spiral inductors was varied to determine the influence of this parameter on the occurring phenomenon and on the emission power between the spiral inductors between 0.05 mm – 5 mm. Each spiral inductor has 10 turns.

Models were also constructed for the spiral inductor ensemble with the emitter on a ferrite layer (Fig. 3 b)) and for the spiral inductor ensemble with the emitter and receiver on ferrite layers (Fig. 3 c)).

The implemented wireless power system is made from: two copper spiral inductors and ferrite layers. The geometrical dimensions of the model are: turn width, w = 0.45 mm, distance between the turns, s = 0.05 mm, thickness of the turn, t = 0.35 mm, exterior diameter of the spiral inductor 1.85 mm and interior diameter of the inductor 5.95 mm. The ferrite layer has a thickness of 0.4 mm and the length of 18 mm, having a square shape.

After constructing the model, a current source is placed on the emitter spiral inductor.

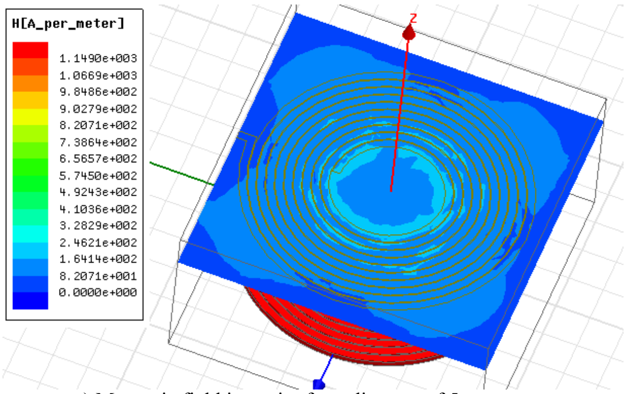
The study aims at determining the following parameters: mutual inductance of the spiral inductors, magnetic field intensity distribution and magnetic induction distribution for different distances between the two spiral inductors.

III. The Analysis of the Influence of the Distance Between the Two Spiral Inductors on Their Specific Parameters

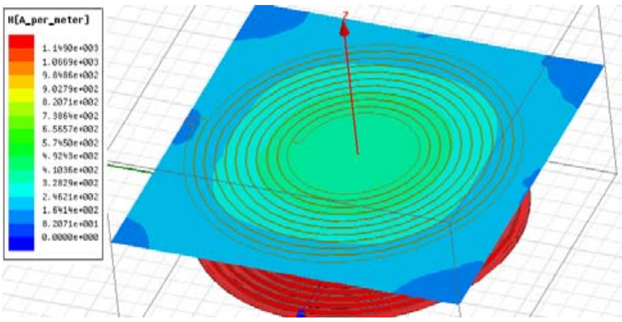
A. Power system having the emitter and the receiver inductors without ferrite layer

In this study, the influence of the distance between the spiral inductors in the initial model without the ferrite layer is presented and analysed. Five different distances were considered between the spiral inductors and the magnetic field intensity distribution on the receiver can be observed in Figure 9.

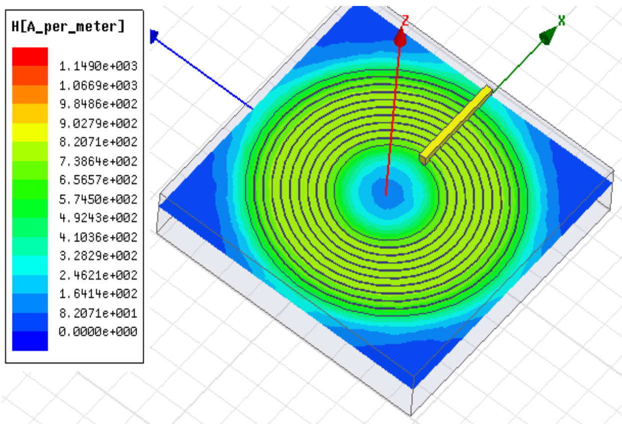
It can be observed that the magnetic field is concentrated inside the spiral inductor, but high values can be observed also between the turns and outside the spiral inductor. The values increase with the decrease of the distance between the emitter and the receiver inductor.



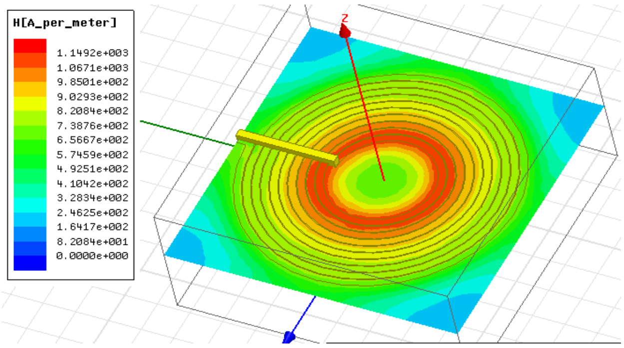
a) Magnetic field intensity for a distance of 5 mm



b) Magnetic field intensity for a distance of 3 mm

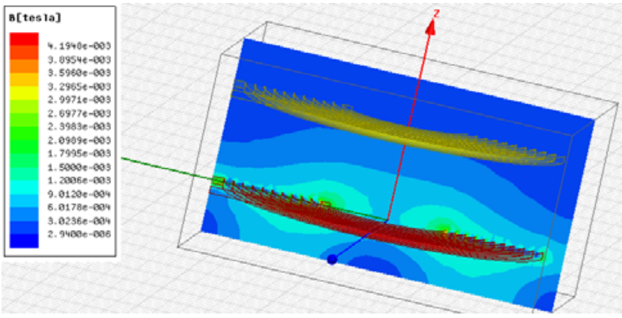


c) Magnetic field intensity for a distance of 0.2 mm

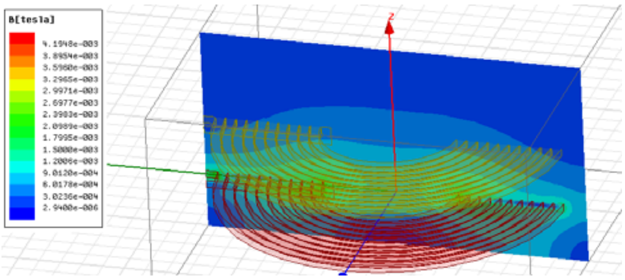


d) Magnetic field intensity for a distance of 0.05 mm

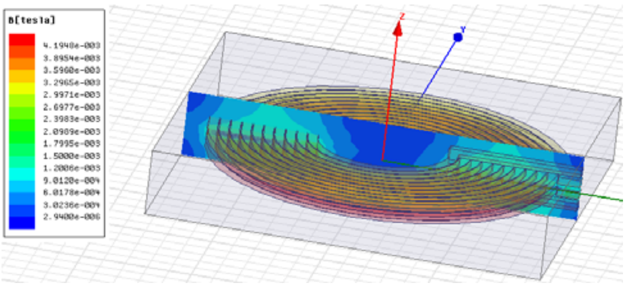
Fig. 9. Magnetic field intensity for different distances between the two spiral inductors considered.



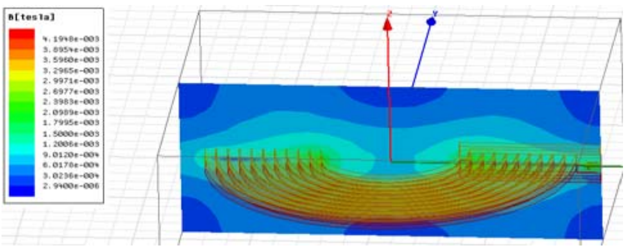
a) Magnetic induction for a distance of 5 mm



b) Magnetic induction for a distance of 3 mm



d) Magnetic induction for a distance of 0.2 mm



e) Magnetic induction for a distance of 0.05 mm

Fig. 10. Magnetic induction for different distances between the two spiral inductors considered.

It can be said that the distance between the two spiral inductors influences the magnetic induction value, but the 2 parameters don't vary linearly due to the parasitic parameters present in the model.

The values obtained for the mutual inductance of the structures considered can be seen in Table II.

TABLE II.
INDUCTANCE VALUES FOR THE DISTANCES BETWEEN THE INDUCTORS WITHOUT FERRITE

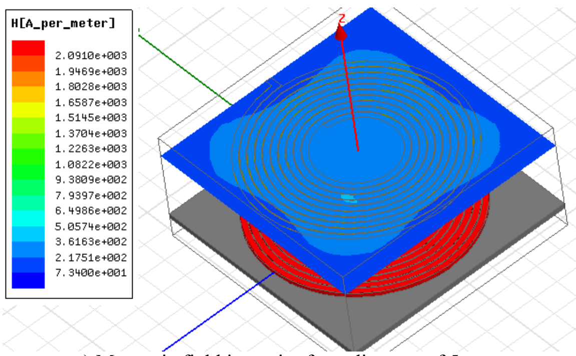
Distance	Mutual Inductance [nH]
5 mm	95.116
3 mm	253.09
1 mm	290.65
0.2 mm	304.17
0.05 mm	685.9

B. Power system having the emitter inductor on a ferrite layer

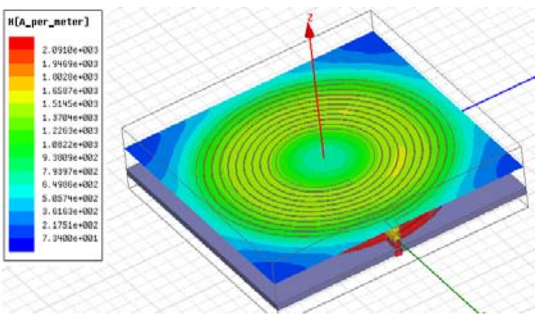
The model considered for this study can be observed in Fig. 3 b). Through the second power system proposed, it has been tried to improve the performance, aiming to find a model in which the voltage induced, thus the inductance, in the receiver to be higher. In this case, the only difference from the previous case is the fact that the emitter inductor is located on a ferrite core. As in the previous case, the specific parameters were determined and analysed.

In Figure 11 the magnetic field in the receiving spiral inductor in three of the five analysed structures is presented. The values increase with the decrease of the distance between the emitter and the receiver inductor as in the previous analysed case.

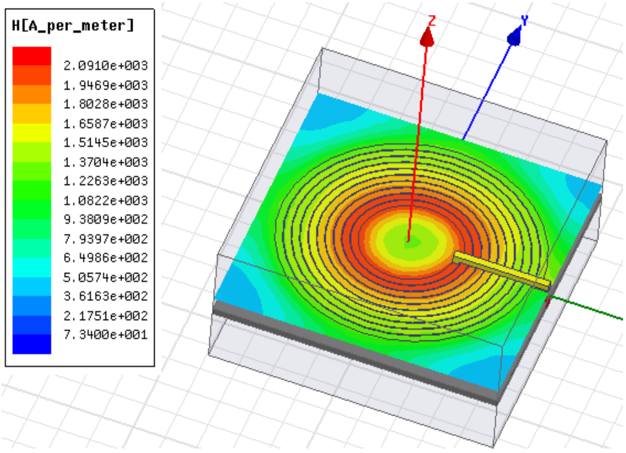
Table III contains the values of the mutual inductances of the analysed spiral inductors.



a) Magnetic field intensity for a distance of 5 mm



b) Magnetic field intensity for a distance of 1 mm



c) Magnetic field intensity for a distance of 0.05 mm

Fig. 11. Magnetic field intensity for different distances between the two spiral inductors considered and the emitter on a ferrite layer.

TABLE III.
INDUCTANCE VALUES FOR THE DISTANCES BETWEEN THE INDUCTORS WITH THE EMITTER ON A FERRIT LAYER

Distance	Mutual inductance [nH]
5 mm	180.2
3 mm	335.57
1 mm	639.22
0.2 mm	701.29
0.05 mm	1193.2

C. Power system having the emitter and receiver inductor on a ferrite layer

Fig. 3c) presents the model considered for this study, where both the emitter and the receiver are placed on ferrite layers.

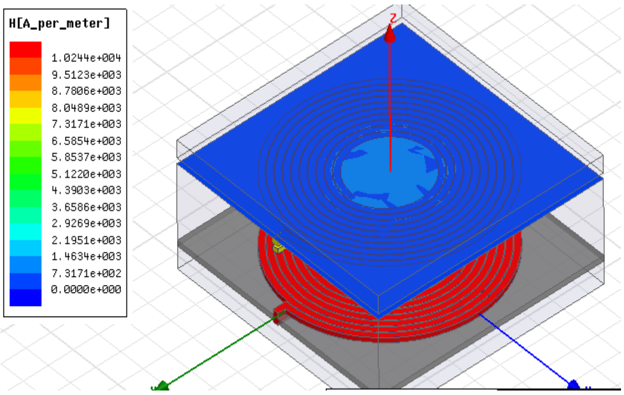
In Fig. 12 the magnetic field intensity is presented for the 5 different distances between the spiral inductors. The conclusion remains the same as for the previous studies, but the maximum value of the magnetic field increases.

The magnetic induction values in the structure are very low, regardless of the distance between the two spiral inductors, this is why the representations are not included.

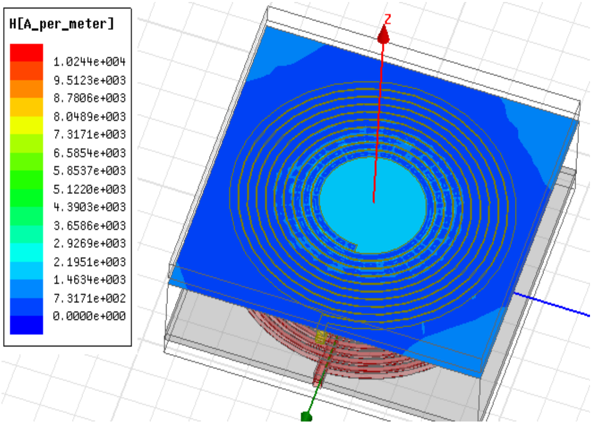
The values obtained for the inductance of the structures considered can be seen in Table IV.

A graph representing the mutual inductance for the three considered structures is constructed and can be seen in Figure 13.

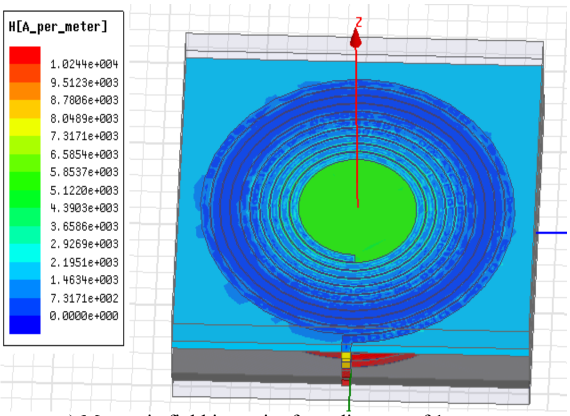
As it can be seen the values of the mutual inductances generally increase with the decrease of the distance between the spiral inductors for all 3 cases considered. Also, it can be noticed that the values for the structure where the emitter spiral inductor is placed on a ferrite layer are higher, while the values for the third structure, the one where the emitter and receiver spiral inductors are both on ferrite layers, are the highest. The difference between the values for the three cases considered increases even more when the spiral inductors are closer.



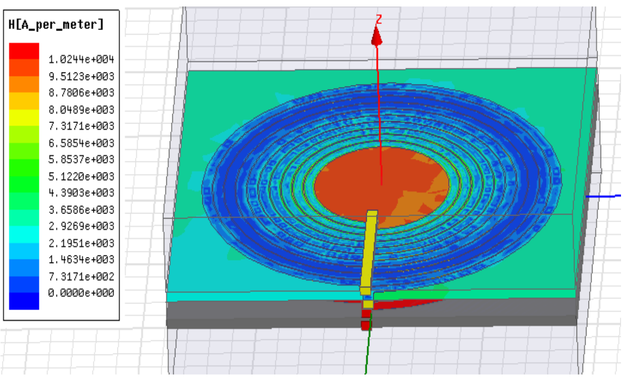
a) Magnetic field intensity for a distance of 5 mm



b) Magnetic field intensity for a distance of 3 mm



c) Magnetic field intensity for a distance of 1 mm



d) Magnetic field intensity for a distance of 0.05 mm

Fig. 12. Magnetic field intensity for different distances between the 2 spiral inductors considered and the emitter on a ferrite layer.

TABLE IV
INDUCTANCE VALUES FOR THE DISTANCES BETWEEN THE INDUCTORS WITH THE EMITTER AND RECEIVER ON A FERRITE LAYER

Distance	**Mutual inductance [nH]**
5 mm	466.44
3 mm	1004.6
1 mm	2760.9
0.2 mm	4450.5
0.05 mm	4708.3

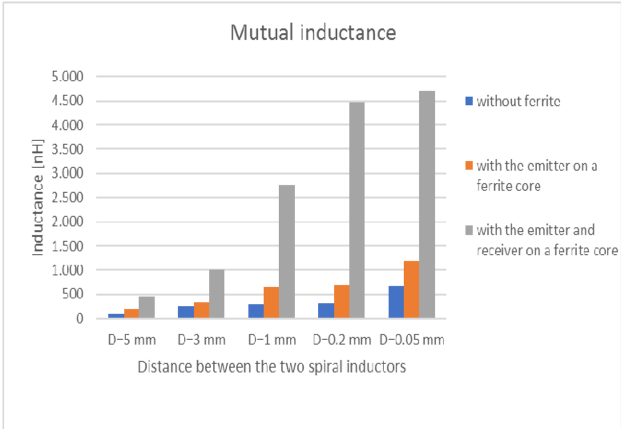


Fig. 13. Mutual inductance values for the spiral inductors in the three considered cases.

As it can be seen the values of the mutual inductances generally increase with the decrease of the distance between the spiral inductors for all 3 cases considered. Also, it can be noticed that the values for the structure where the emitter spiral inductor is placed on a ferrite layer are higher, while the values for the third structure, the one where the emitter and receiver spiral inductors are both on ferrite layers, are the highest. The difference between the values for the three cases considered increases even more when the spiral inductors are closer.

IV. Conclusions

The present study aims at improving wireless power systems. In order to achieve this purpose, ferrite layers are inserted in the initial structure constructed from two monolayer spiral inductors representing the emitter and the receiver. Also, the distance between the two spiral inductors is varied to determine how much it influences the specific parameters for the two inductors.

The proposed wireless power system was practically constructed and the voltage induced in the receiver inductor was measured and analysed. The voltage value increased for the structures with the ferrite layers and decreased with the increase of the distance between the inductors.

After constructing the model, an idea about the parameter influence can be drawn, but in some cases like the variation of the distance between the spiral inductors, the parameters are hard to be varied due to the small dimensions of the model. Thus, the numerical modelling of the system is the easier way to determine their influence.

After modelling and simulating the three models considered with a 3D numerical modelling program, some general conclusions can be drawn. It can be observed that the magnetic field is concentrated inside the spiral inductor, but high values can be observed also between the turns and outside the spiral inductor. The values increase with the decrease of the distance between the emitter and the receiver inductor. After inserting one or two ferrite layers in the model the values increase, the highest values being observed in the model where both emitter and receiver are on ferrite layers and the distance between them is 0.05 mm.

The values of the inductances generally increase with the decrease of the distance between the spiral inductors for all 3 cases considered. Also, it can be noticed that the values for the structure where the emitter spiral inductor is placed on a ferrite layer are higher, while the values for the third structure, are the highest. The difference between the values for the three cases considered increases even more when the spiral inductors are closer.

Knowing that the mutual inductance is proportional to the voltage induced in the receiver, it can be said that analysing both the practical results and the results from the numerical modelling of the structure, it can be said that they are in accordance.

ACKNOWLEDGMENT

This work was supported by a grant of the Romanian National Authority for Scientific Research and Innovation, CNCS – UEFISCDI, project number PN-II-RU-TE-2014-4-0199.

Contribution of authors:

Firs author – 20%

First coauthor – 20%

Second coauthor – 20%

Third coauthor – 20%

Forth coauthor – 20%

Received on Mars 11 ,2018
Editorial Approval on September 1, 2018

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