Practical Realisation and Analysis of Spiral Inductors for Wireless Power Supply Systems

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Abstract*– Increasing the number of electric / electronic devices fed with electrical energy, has led to a series of different chargers and a mixture of wires spread through the house or office. For a long period of time the concept of charging without any direct connection through wires was avoided, but now it is gaining more interest in order to make electricity charge more flexible and easier to use. In this context, the work has as main objective, the practical realization and analysis of some power systems for electrical and electronic devices. Therefore, multiple types of spiral inductors were created and analyzed in order to achieve a feeding device with higher performance.*

Keywords – *spiral inductors, receiver, transmitter, induced voltage.*

1. INTRODUCTION

The explosive and continuous development of modern applications which are operating at gigahertz order frequencies with the size and weight as low as possible in the communications and wireless telecommunications, wireless biomedical applications (monitoring, command, power wireless medical implants) and the vastness of industrial applications has generated an increased interest for the spiral inductors.

A wireless power system involves a transfer of energy between two or more objects by means of an electromagnetic field, as shown in Figure 1 [8]. The technology requires two spiral inductors: a transmitter and a receiver, and an alternating current is passed through the transmitter spiral inductor generating a magnetic field. This, in his turn, induces a voltage in the receiver spiral inductor, which can be used to power a mobile device or charge a battery. In this practical study, both the transmitter and receiver spiral inductors are made of copper, and the rectifier is used to convert the alternating current signal to DC signal.

Transmission of electricity without wires is an emerging technology which ensures charging consumers, eliminating cables, as Wi-Fi replaces a cable to connect to the Internet. In an ideal system where there is a loading platform and a phone placed on it, everything works fine, but this is the ideal case. In practice, we could put accidentally a coin on the charger, and so a current could appear in it.

From here the first problems appeared, problems which are resolved largely through the standardization of wireless charging. The most popular wireless charging standards are: Qi – developed by the Wireless Power Consortium, Rezence – developed by the Alliance for Wireless Power, PMA - developed by the Power Matters Alliance.

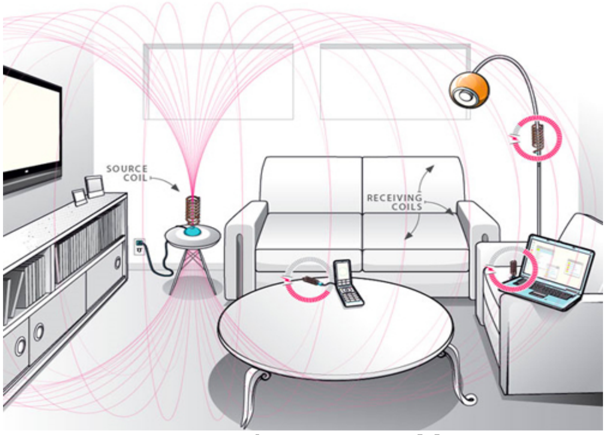

Fig. 1 Wireless power system [8]

2. SPIRAL INDUCTOR CONSTRUCTION

The study aims at the practical realization of a wireless power supply system that consists of a transmitter system and the receiver system, as shown suggestively in the image from Figure 2 [7] in which, as an example, the wireless system for supplying a mobile phone is presented. Starting from this example, it was found that basically the wireless device contains a spiral inductor which is charging and induces a voltage through the spiral inductor of the phone, voltage which charges the phone. Thus, the first wireless system achieved contains two spiral inductors, one that plays the role of the transmitter and another that acts as a receiver.

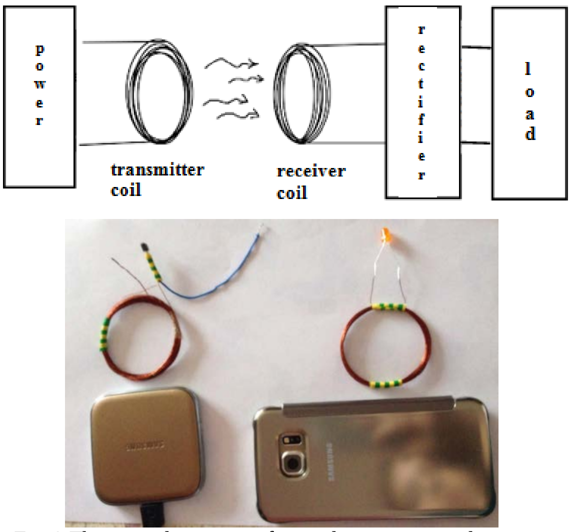

Fig. 2 The general structure of a wireless power supply system

The spiral inductor is made by winding a conductive wire (usually copper) on a core. This core can be ferromagnetic, in this case the spiral inductor having a high inductance, or it may be non-ferromagnetic, or even it can be missing, in this case the spiral inductor having low inductance. In alternative current operation, a spiral inductor has an inductive reactance dependent on the frequency of the alternative current. The construction of the spiral inductors depends on a series of factors such as: the destination of the spiral inductor, the inductance value, the quality factor, mode of assembly and shielding, etc. and characterized by: the diameter (section) of the conductor, number of turns, pitch, number of layers and sections.

After the way the the winding turns are disposed on the carcass, the spiral inductor can be: with a single layer or with multiple layers (multilayer). The winding in a single layer is achieved with a simple technology for winding turn beside turn or with spaces between the turns (pitch winding). The pitch windings are used, generally, to achieve spiral inductors with low inductance value. For windings made with pitch (constant or variable) uninsulated wires are usually used, resulting small values for the parasitic capacitance. For the multilayer windings the self inductance value is higher, requiring the same area. For this type of winding there is a higher value of the parasitic capacitance and the risk of electric perforation by joining the windings with large differences of potential is increased. The reduction of these inconveniences can be obtained through various ways to arrange the spiral inductor’s turns. Thus, the increase of the perforation voltage can be obtained by increasing the distance between the turns of the spiral inductor and by isolation inserted between the layers. The increase of the distance between turns and layers also allows a reduction of the parasitic capacitance. The screen is intended to reduce the electric or magnetic field around the spiral inductor - from the spiral inductor to the outside and from the outside to the spiral inductor. It is used only for spiral inductors without core and for the ones with core, but with open magnetic circuit or large air gap. For the spiral inductors with closed magnetic circuit the shielding is not required because the magnetic field is concentrated inside the magnetic core.

3. POWER SUPPLY SYSTEMS HAVING THE TRANSMITTING SPIRAL INDUCTOR WITH / WITHOUT MIDPOINT TAP

The wireless power supply system that was considered the starting point of this research is from the Qi category, platform powered at a 5 V DC voltage and a 2 A DC, the receiver being able to provide a voltage of 5 V and a maximum direct current of 0.8 A. In the present study, several spiral inductor models were built and proposed having as a starting point spiral inductors made from copper and up to spiral inductors made from multicore cable, aimed at increasing their transmission power. Further, wireless power systems made by the authors having the transmitter spiral inductor with and without midpoint tap are presented, together with practical results.

3.1 Power supply system having the transmitting spiral inductor made of copper with midpoint tap

The transmitting spiral inductor is made of enamelled copper conductor with a diameter of 1 mm, 24 turns, the inductance value 48.7 μH, midpoint tap and inside diameter of the spiral inductor of 4.8 cm. The receiver spiral inductor is made from the same type of copper conductor, having 22 turns, the inside diameter of the spiral inductor value 4.8 cm and the inductance value 41.5 μH. In order to assess these data in Figure 3 and Figure 4 an image with the interior diameter of the copper conductor, and the value of the inductivity measured for the transmitters spiral inductor and receivers is presented.

Fig. 3 Details of the transmitting spiral inductor

Fig. 4 Details of the receiver spiral inductor

Figure 5 presents the electrical scheme of the first wireless power supply system proposed to be analyzed.

Thus it can be seen that it contains two spiral inductors mentioned above, one having the role of transmitter, the other the role of receiver, a transistor 2N2222, a battery of 1.5 V used to power the generator spiral inductor and a led through which it is desired to show that a voltage is induced in the receiver spiral inductor. The transmitting spiral inductor has two ends connected to the base and to the 1collector of the transistor 2N2222. The main characteristics of the transistor 2N2222 are: collector-emitter voltage 25 V, 30 V collector-base voltage, the current from collector is 0.8 A, 350 mW dissipation, the current gain in bandwidth is 650 MHz, NPN type. As mentioned above, initially power is supplied by a battery of 1.5 V, the plus of battery is connected to the midpoint tap of the transmitting spiral inductor and the minus of battery is connected to the emitter of the transistor 2N2222.

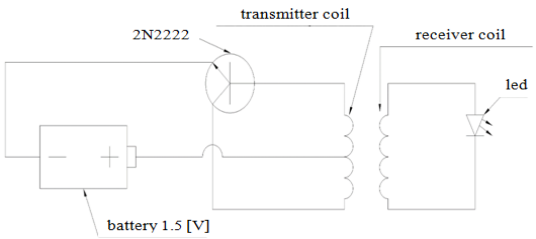

Fig. 5 Electrical scheme of the first power supply system

For starters, the transmitting spiral inductor is powered by a battery, and the receiver spiral inductor is superimposed over the transmitting spiral inductor without any distance between them. It can be seen in Figure 6 that in this case in the receiver spiral inductor a voltage of 1.636 V was induced, sufficient to turn on the LED attached to it. Further the influence of the distance between spiral inductorson the value of the induced voltage is followed, more specifically it is desired to identify up to what distance between spiral inductor voltage in the receiver spiral inductor is induced.

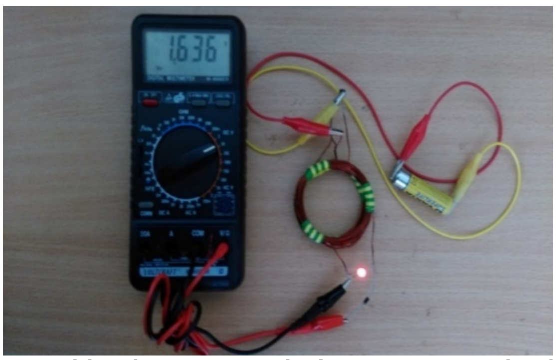

Fig. 6 Model 1: The receiving spiral inductor is superimposed on the transmitter spiral inductor

Further different placement situations of the two spiral inductors were analyzed following the induced voltage value and the light intensity of the LED for different distances between these two.

Analyzing the results obtained and presented in Table 1, it can be observed that in the first case analyzed, ie the situation in which the receiver spiral inductor is superimposed over the generator spiral inductor, the induced voltage in the receiver is 1.63 V, and with the increase of the distance between transmitter and receiver the induced voltage decreases, as expected, but it is interesting to note that the system allows the feeding of the LED in the case in which the two spiral inductors are located at a distance one from another.

Table 1 - Results achieved in the case of the first system proposed

Distance, cm	Measured Voltage,V
0	1.636
1.7	1.136
4.3	0.868

3.2 Power supply system having the transmitting spiral inductor made of multicore cable with midpoint tap

By means of the second power system proposed, the improvement of its performance was proposed, aiming to achieve a model for which the voltage induced in the receiver to have a higher value and also the distance up to which is induced voltage to be increased. In this case the generating spiral inductor is made of multicore cable, and in the case of the receiver spiral inductors, some were manufactured from enameled copper conductors, others from multicore cable, as it will be presented.

The transmitting spiral inductor is made from 5 m long multicore cable, with a 98.2µH inductance and a midpoint tap, and the receiver spiral inductor is also made from 1 m long multicore cable, having 1.1 µH inductance, as shown in Figure 7.

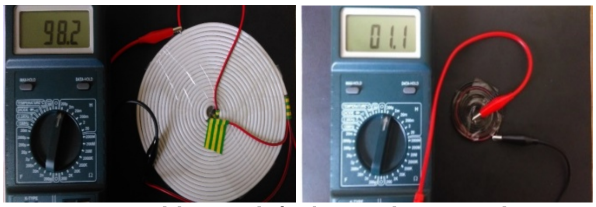

Fig. 7 Model 2: Details for the second power supply system

In Figure 8 is present the electrical scheme for the second wireless power supply system proposed for analysis.

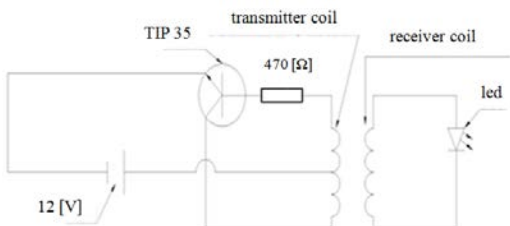

Fig. 8 Electrical scheme from the second power accomplished system

It can be observed that the system contains the two spiral inductors mentioned above, one having the role of a transmitter, and the other having the role of a receptor, a TIP 35 transistor, 12 V power supply system, a resistance of 470 Ω and a LED / strip of LEDs through which it is wanted to show that voltage is induced in the receiver spiral inductor.

For starters, the transmitting spiral inductor is powered by a source of 12 V, and as a receiver the spiral inductor proposed in the first system shown, namely the one from enamelled copper, is powered. In this case, first the induced voltage measurement in the receiver for the case in which the two spiral inductors are superimposed was made, and then for different distances between the receiver and the transmitter the same measurement was made. Thus, in the case of overlapping the receiver over the transmitter, the voltage measured in receiver was 16.44 V, next if there is a distance between them of 4.3 cm the voltage is 2.75 V; these results are illustrated in Figure 9. Tests were made for different distances between the two systems until the distance of 11.9 cm where the voltage measured in the receiver was 0.13 V.

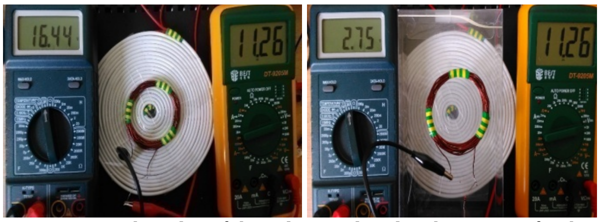

Fig. 9 The value of the voltage induced in the receiver for the case in which the spiral inductors are superimposed and is at 4.3 cm

Further the case in which the receiving spiral inductor is made of multicore cable was analyzed, in the first stage the receiving spiral inductor being superimposed over the transmitter spiral inductor with no gap between them. The voltage and current from the receiver measurement were followed, receiver which, in these analyzes, is powering a LED band receiving voltage via the transmitter powered by a 12 V battery. It can thus be seen from the measurements made that the voltage with which is powered the LED strip, ie the induced voltage in the receiver, is 6.31 V and the current absorbed by the LED band 22.2 mA, as presented in Figure 10.

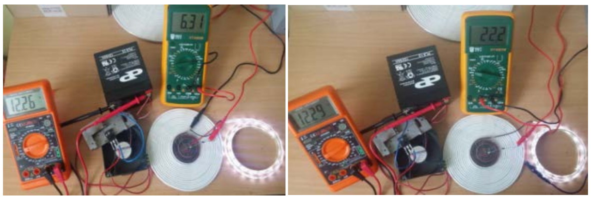

Fig. 10 The current and the voltage induced in the receiver in the case in which the transmitter is powered with 12 V

Following the results obtainig for the second system proposed, having the receiving spiral inductor from the first system, it was observed that the induced voltage in the case in which the receiver is superimposed over the transmitter is about 16.44 V and the voltage is induced up to a distance of 11.9 cm between transmitter and receiver, unlike the first system proposed, where the maximum induced voltage is 1.63 V.

3.3 Changing the equivalent circuit of the first power supply system proposed in order to amplify the signal

Given the results obtained in the first two proposed systems, next the achievement of a wireless system with dimensions as small as possible and higher performances is aimed. For this purpose, for the achievement of this system the same spiral inductors from the first system proposed were used, shown in Figure 3 jand Figure 4.

The electrical scheme of the third power supply system proposed for analysis is presented in Figure 11. Thus it can be seen that it includes those two spiral inductors mentioned above, one having the role of transmitter and the other the receiver, two MOSFET IRFP 250 transistors, two 120 Ω resistors, two 12kΩ resistors, two Zener diodes, two UF4007 diodes and a LED/ LED strip, through which it is wanted to show that a voltage is induced in the receiver spiral inductor.

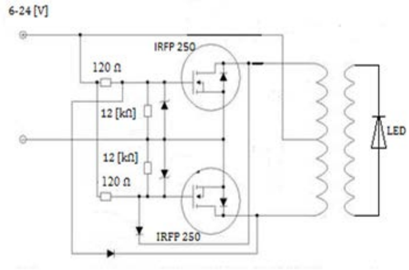

Fig. 11 Electrical scheme of the third system realized

After the realization of the electrical circuit, the determination of the induced voltage in the receiver, depending on the voltage and the current debited by the rectifier was followed. Thus, when powering the transmitter with 6V and 25 Ah, the voltage obtained in the receptor was 3.7 V. Gradually increasing the value of power , for example 6 V and 80 Ah, the voltage obtained in the receptor was 4.5 V, and with the increase of the power to 12 V and 25 Ah, the voltage obtained in the receptor was 6.7 V; finally at a power of 12 V and 80 Ah, the voltage obtained in the receptor was 8 V as shown in Figure 12. Also it can be seen that the induced voltage in the receiver is sufficient to supply the LED strip shown in the image below.

Fig. 12 The voltage for powering the transmitter with 12V and 80Ah

Further, the current from the receiver circuit depending the voltage and the current debited by the rectifier was desired to be determined. At 6V and 25Ah the measured current value in the receiver was 11.8 mA. At 6V and 80 Ah the current measured in the receiver, in the second case was 30.6 mA. At 12 V and 25 Ah, the current value measured in the receiver reaches 103.7 mA and finally at 12V and 80 Ah, the current measured in the receiver was 173.6 mA as shown in Figure 13.

Fig. 13 The current value from the receiver, for the case in which the transmitter is powered with 12V and 80Ah

The results obtained for the third power system proposed, using the transmitter spiral inductor and the receiver spiral inductor from the first system, are summarized in Table 2.

Table 2 -Results obtained in the case of the 3rd system proposed

Power supply	Measured voltage, V	Measured current, mA
6 V –25Ah	3.7	11.8
6 V– 80Ah	4.5	30.6
12 V –25Ah	6.7	103.7
12 V– 80Ah	8	173.6

Following these results, can be seen that if the transmitter power supply is changed to the following possible situations 6 V and 25 Ah, 6 V and 80 Ah, 12 V and 25 Ah, 12 V and 80 Ah both voltage and current measured in the receiver increase.

Also, comparing the results with those obtained in this case with the ones obtained for the first system proposed it can be seen that the induced voltage in the receiver increases, thus using the model of the third system, the performances of the wireless power system increase.

3.4 Power supply systems having the transmitting spiral inductor without midpoint tap

In the fourth power supply system proposed eliminating the midpoint tap of the transmitting spiral inductor and keeping or even improving the system performances was followed. To accomplish these objectives, in this case the generating spiral inductor respectively the receiving spiral inductor were made of enameled copper, more precisely the spiral inductors from the first model will be used again, but not powered through the midpoint tap, as presented further on.

Figure 14 shows an image with the fourth power supply system proposed for analysis.

Thus it can be seen that it contains two spiral inductors, two MOSFET IRFP 250, two 120Ω resistors, two 12kΩ resistors, two Zener diodes, two UF4007 diodes and an LED / strip of LEDs with which it will be shown that voltage is induced in the receiver spiral inductor.

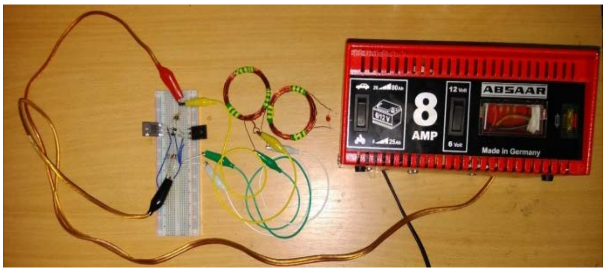

Fig. 14 The fourth power supply system achieved

In this paragraph was monitored the measurement of the voltage obtained in the receiver depending on the voltage and current delivered by the rectifier. For example, Figure 15 shows the case in which the transmitter is powered with 12V and 80Ah, case in which the obtained voltage in the receiver was 6 V.The results obtained for the other cases analyzed are centralized in Table 3.

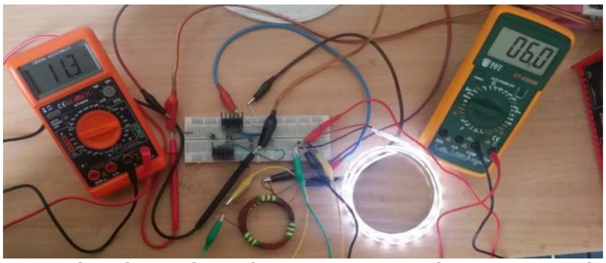

Fig. 15 The voltage value in the receiver to power the transmitter with 12V and 80 Ah

It was also desired to determine the current from the receiver circuit depending on the voltage and current debited by the rectifier. For example, Figure 16 shows the transmitter powered with 12V and 80Ah, case in which the measured current in the receiver is 8.92mA. In Table 3 the results obtained for other powering situations analyzed in the present study are presented.

Fig. 16 Current value in the receiver for powering the transmitter with 12V and 80 Ah

Table 3 -Results obtained in the case of the 4th system proposed

Power supply	Measured voltage, V	Measured current, mA
6 V –25Ah	7.5	0.107
6 V– 80Ah	7.7	0.614
12 V –25Ah	7	5.21
12 V– 80Ah	6	8.92

Following the results shown in Table 4 for the fourth power supply system proposed by the authors, it was observed that in case when the transmitter power supply is changed to the following possible situations 6 V and 25 Ah, 6 V and 80 Ah, 12 V and 25 Ah, 12 V and 80 Ah, the measured voltage in the receiver drops and measured current in receiver increases.

4. CONCLUSIONS

In this work the main objective was the practical realization and analysis of wireless power supply systems. Thus, starting from the wireless power device of the mobile phone, 4 power supply systems models were built and analyzed, initially using for their construction a transmitting spiral inductor with midpoint tap and then without the midpoint tap.

From the results obtained for the first model it can be seen that when the receiver spiral inductor is superimposed over the generating spiral inductor the induced voltage in the receiver is 1.63 V.

In order to improve the performance of power systems, the construction of the second power system the receiver spiral inductor of the first system was used, and the transmitting spiral inductor was this time made from multicore cable with midpoint tap, or amplifier circuit modified from the first case. It was observed, in this case, that the induced voltage for the case in which the receiver is superimposed on the transmitter is about 16.44 V and the voltage is induced to a distance of 11.9 cm between the transmitter and receiver, unlike the case of the first wireless system proposed where the maximum induced voltage was 1.63 V.

In the case of the third wireless power system, the receiver spiral inductor and the transmitter spiral inductor from the first system were used, improving in this case the amplifier circuit. From the results obtained for this case it was observed that changing the transmitter power supply at the following possible situations 6 V and 25 Ah, 6 V and 80 Ah, 12 V and 25 Ah, 12 V and 80 Ah leads to the increase of the voltage and current measured in the receiver.

And finally, in the fourth wireless power system the receiver spiral inductor and the transmitter spiral inductor from the first system were used, but without the midpoint tap, and the amplifier circuit from the third system. Analyzing the results obtained for a fourth wireless system proposed it was observed that in the case in which the power supply of the transmitter is modified, in the presented situations and for the third power supply system, the measured voltage in the receiver drops, and the measured current in the receiver increases.

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