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A NEW MAGNETICALLY COUPLED WIRELESS POWER SYSTEM USING DOMINO PRINTED SPIRAL COILS AND MULTIPLES LOADS

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This paper presents a study of a wireless power transfer system that uses magnetic coupled printed square coils in association with a straight retransmission domino system and manifold loads. An experimental study using multiples retransmitter coils, multiple loads, and combinations of both cases was realized. The total efficiency of the system and the efficiency of each receptor coil were compared with direct transmission system using only two coils.

Introduction

The wireless power transfer technology is already a reality, diverse models equipment for charging cell phones or car batteries through inductive coupling are available at affordable prices. However, the inductive coupling has as main characteristic the short distance operation, not being possible to make a freeload charger (charging in movement, for example), since is necessary to keep the unit on the transmitting base. The major challenge of current research is to increase the distance of operation, maintain a good power transfer, an elevated efficiency and the ability to power multiples loads. Several studies are made to increase the transmission distance without reducing efficiency. The main lines of research are strongly coupled magnetic circuits [1], use of metamaterial or fishnet metamaterial [2] and multiple resonators [3-5]. Especially in [3] it were used eight resonators, with 155 mm of radius and 11 turns, equally spaced with a total distance of 2.1 meters. Resonators were arranged in a straight domino way and the achieved system efficiency was 40%. Based in the multiple resonator studies, in this work, a new wireless power system topology is proposed. The system is based in strongly coupled magnetic planar squared printed coils arranged in a straight domino way. Retransmitter coils are used in order to increase the system efficiency over longer distances. In addition, a study considering loads placed on different points of the system, being possible to observe the behaviour of the system with multiple loads, is carried out.

System presentation

One coil of the wireless power transfer system presented in this work is illustrated by Fig. 1 (a) and for which the dimension are presented in Table 1. The squared coil was printed in a FR-4 substrate and its first two resonances was found in 46 MHz and 93 MHZ, simulated in ADS (Advanced Design System, Agilent), and 44 MHz and 93 MHZ, when measured. The Fig 2 (a) compares the simulated and measured values for the return loss of the coil, once the return loss is the most important parameter for measuring the efficiency of wireless transmission system. As can be seen the resonance frequency is high due to the low parasitic capacitance. Work in low frequency is advantageous due the build facility the system, low interferences and increase the amount of power transmitted. In order to reduce the resonance frequency a 22 nF capacitor is connected to each drive coil reducing the resonant frequency to 1.77 MHz, as show in Fig 2 (b). The results simulated in ADS and measured are close, however the small differences presented are associated the inaccuracies of build and measure of the system.

The configuration of the transmission wireless system proposed in this work is presented in Figs. 1(b) to 1(f). It is constituted of identical printed coil like that illustrated in Fig. 1 (a) with a 22nF capacitor connected. In the wireless system, each coil can work as transmitter (TC), retransmitter (RC) and load coils (LC). In TC unit the drive coil is connected to the source and inductively coupled to the main coil. Similarly in the LC unit, the drive coil is connected to the load coil and inductively coupled to the main coil. The RC units can work without or with a load connected to the drive coil. In Figs. 1(b) to 1(f) are illustrated all configurations tested is this work where the distances d1, d2 and d3 are varied.

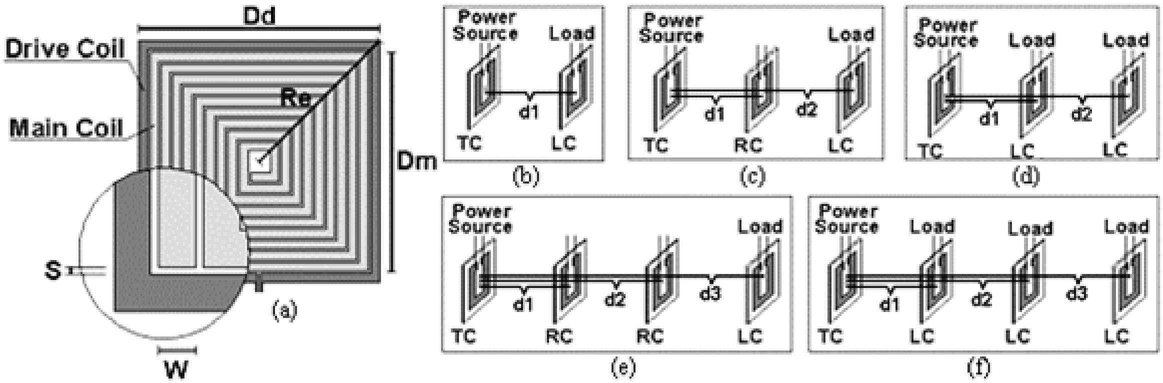

Fig 1. (a) Geometry of each printed coil (b) Direct transmission system (c) System with a resonator and a load coil (d) System with two load coils (e) System with two resonator and one load coils (f) System with three load coils.

TABLE I
DIMENSIONS OF THE COILS

Item	Dimension (mm)
Cooper's thickness (*t*)	0.0175
Track width (W)	5
External coil radius (Re)	92
Separation between spirals (S)	1
Biggest main coil dimension (Dm)	118
Drive coil dimension (Dd)	130

Power system design and results

In this work several case of studies were considered, in order to organize these cases of studies and facilitate the presentation each case illustrated in Figs. 1(b) to 1(f) was identified by a number, the first case of study, Study 01, is the system shown in Fig. 1 (b), the second, Study 02, is the system illustrated in Fig. 1 (c), and successively. Notes that in all cases of study the coils are connected to a capacitor of 22 nF.

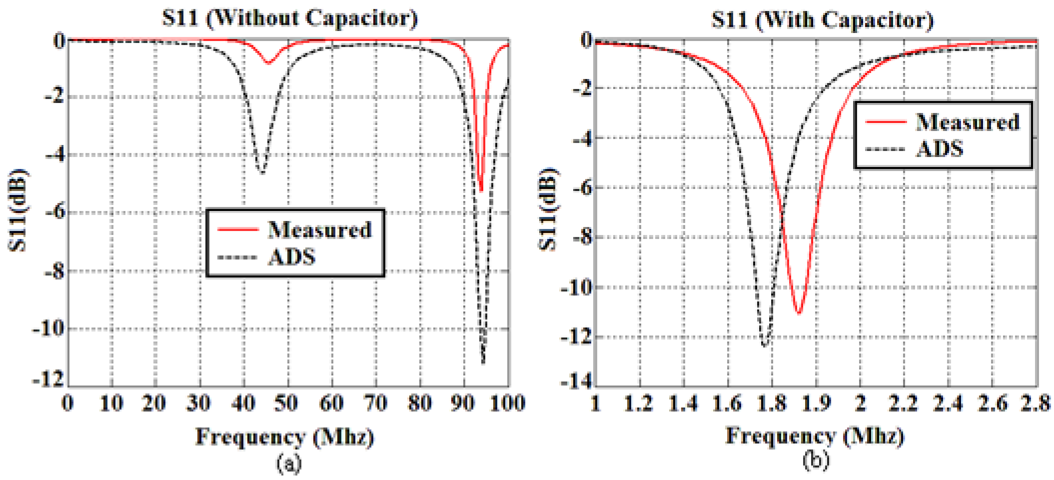

Fig 2. (a) S_{11} without Capacitor, (b) S_{11} with a 22 nF capacitor.

The Study 01 was carried out in order to verify the system efficiency behaviour as function of distance between TC and LC. The measurements were made considering distances multiples of 12 mm. The TC was feed by a signal generator adjusted to operate in 1.77 MHz and the LC was connected to a 47 Ω resistive load. The results obtained are presented in Fig. 3. As expected, the efficiency reduces when the distance between the coils is increased. For d1 = 24 mm was achieved an efficiency of 40%. The result obtained for distance d1 = 144mm will be used in other case of studies to verify the increase in efficiencies values for long distances. To facilitate the presentation of results this results it is, from now, called 144.

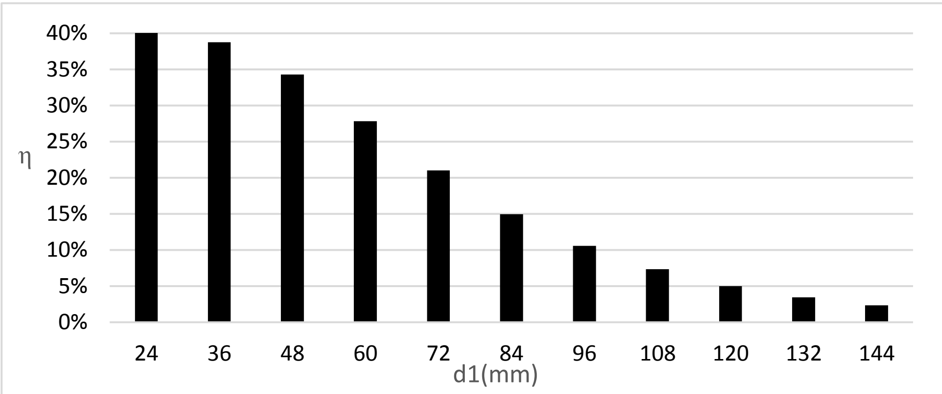

Fig 3. Direct transmission system: Efficiency (η) x d1(mm)

In Study 02 was to introduce a RC coil between the TC and LC. The results obtained are presented in Fig. 4. The use of the RC increased the efficiency in LC in relation to the case of study 144 for all distances investigated, except for the distance d1=124 mm and d2=24 mm. According Fig. 4, the best condition occurs when the distance between the coils are equal, in this situation the efficiency is 4.33 times bigger than the case of study 144.

Another possibility is change the RC by a LC, called Study 03. In this case the system has two output powers and the results obtained are presented in Fig. 5. As can be seen, for all distances investigated, the overall system efficiency (ηLC1+ ηLC1) increases in relation to the case of study 144. It is possible to note that the LC nearest the TC has the highest efficiency and that as the distance increases the efficiency of each LC decreases.

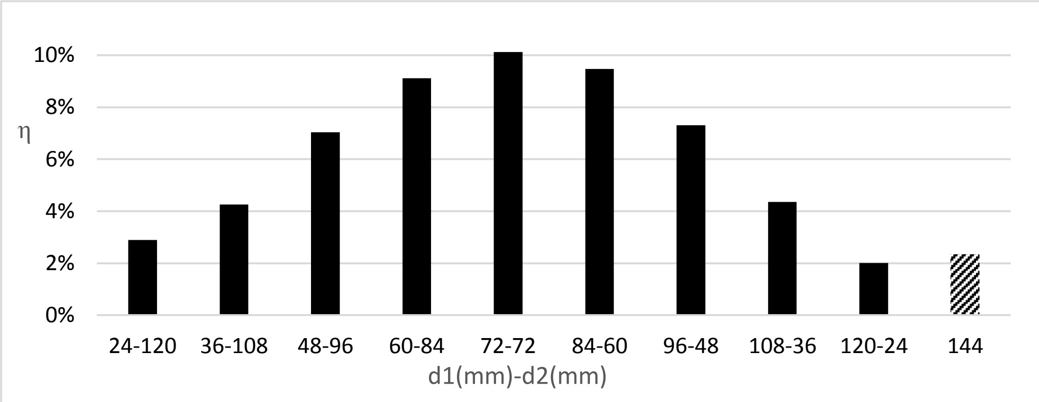

Fig 4. System with a resonator and a load coil: Efficiency (η) x d1-d2(mm)

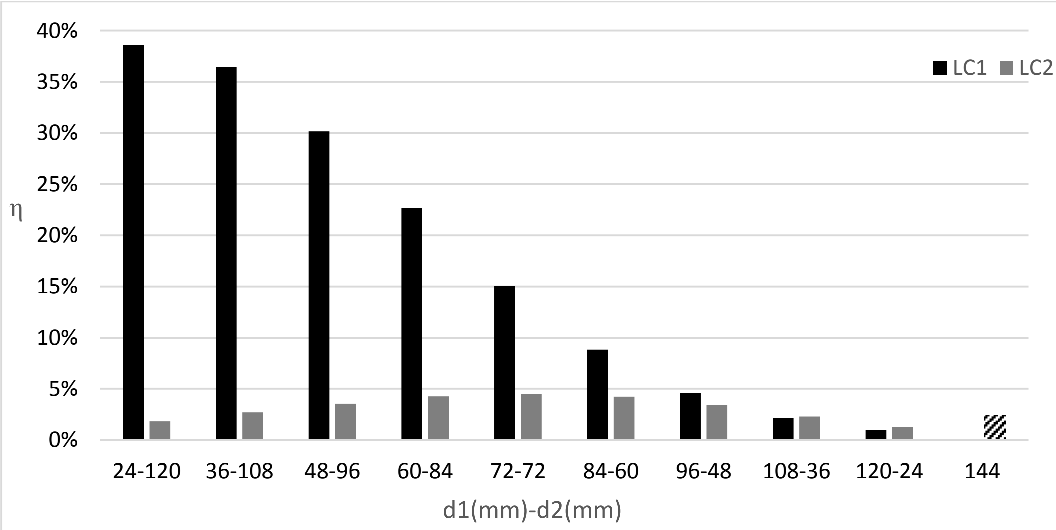

Fig 5. System with two load coils: Efficiency (η) x d1-d2(mm)

In the Study 04 a TC, two RC and a LC were use as illustrated in Fig. 1 (e). The results obtained are illustrated in Fig. 6.As can be observed all tested possibilities provided a gain in efficiency in relation to the case of study 144. The best situation occurs when the coils are equally spaced, d1=d2=d3=48 mm, with a efficiency 5,59 times bigger than the case of study 144.

In the Study 05 the experimental results, considering three load coils each connected to a 47 Ω resistive load, are presented. This is an important study in order to verify the influence of the distance between the coils and the amount of energy available in each one. The results obtained are presented in Fig. 7 where is possible to identify the amount of energy goes to each coil. As all coils are identical, only the distance influences the energy received by each one. As can be noted, for all distances investigated, the overall system efficiency (ηLC1 + ηLC1 + ηLC3) increases in relation to the case of study 144. It is possible to note that the LC nearest the TC has the highest efficiency and that as the distance increases the efficiency of each LC decreases. To achieve greater efficiency in the last LC necessary establish the same distance between the coils.

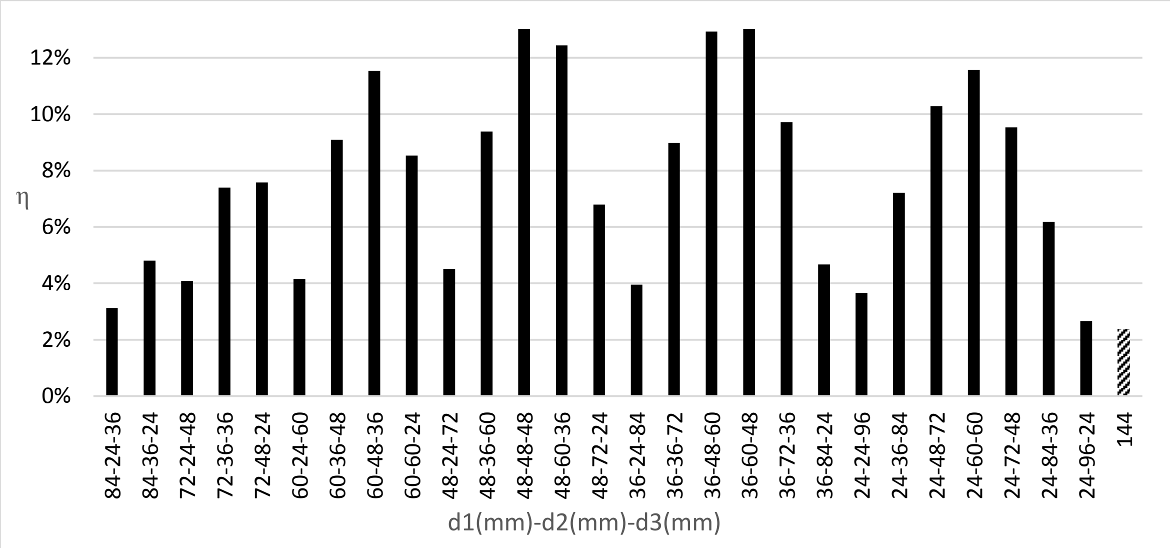

Fig 6. System with two load coils and a resonator: Efficiency (η) x d1-d2-d3(mm)

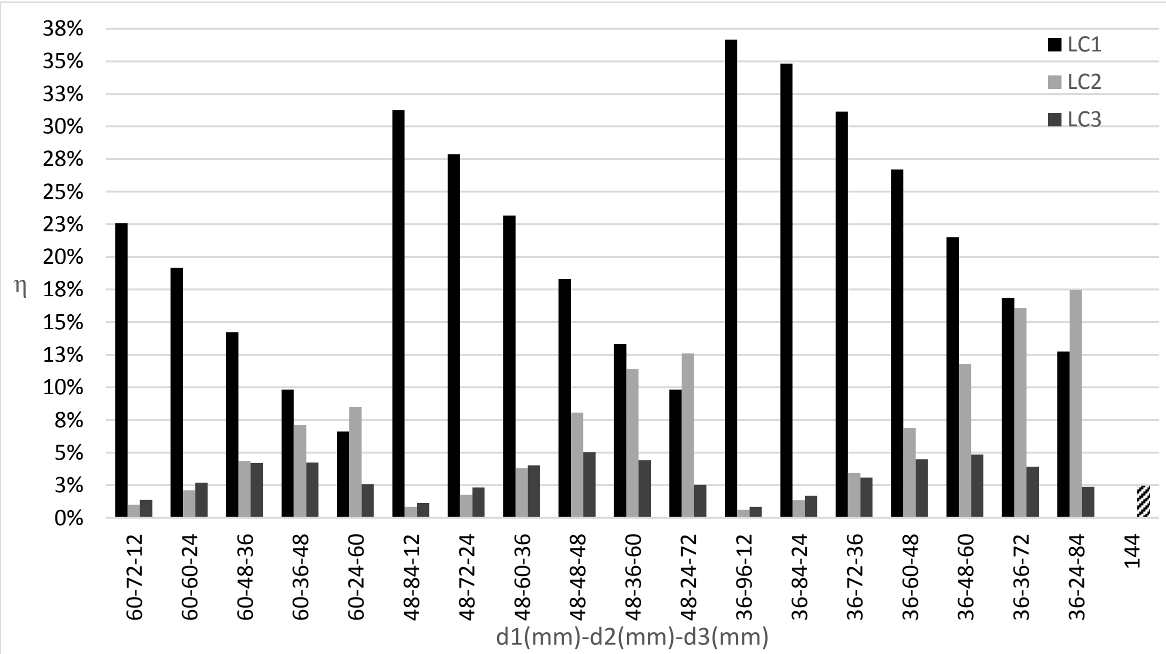

Fig 7. System with three load coils: Efficiency (η) x d1-d2-d3(mm)

The value of the capacitor to set resonance frequency to 1.77 MHz was realized for an individual coil, as illustrated in Fig. 2. When the system is fully analysed, the position of each coil causes a change of the coils parameters, such as mutual inductance and thereby causes a slight shift in the resonant frequency of each coil. In order to demonstrated this fact a graphic of the results for Study 05 with coils equally spaced (d1 = d2 = d3 = 48mm) and varying the frequency is shown in Fig. 8. The analysis of the graphic in Fig. 8 permitted to observe that a small variation in frequency of the TC allows selecting optimum conditions for each LC. The maximum overall efficiency occurs in 1.77 MHz, but with the reduction in the frequency, the second LC efficiency increases while others suffer a reduction. When the frequency is above 1.77 MHz, only the first LC more power. The best results for the third coil occurs near the resonance frequency.

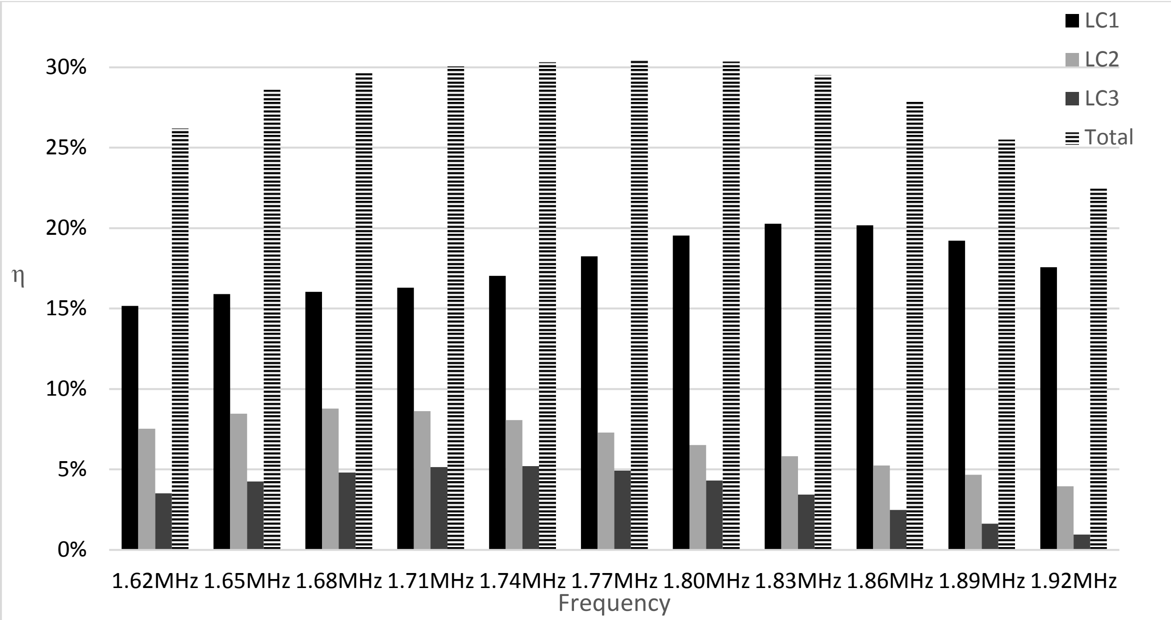

Fig 8. System with three load coils: Efficiency (η) x Frequency

Conclusion

This paper presents results of an experimental work, whose aim is to analyze a wireless transmission system using printed spiral square coils arranged in a domino way. From the experimental analysis performed in this study it was observed that the use of a RC between the TC and LC coils allows increasing the power transmitted to the LC, especially when the RC is located in the middle distance between TC and LC. Connecting a load in the RC, which turns into a LC, the overall system efficiency was increased and it was observed slight increase in last LC eficiency. In order to increase the eficiency values a new RC coil was added to the system. By this configuration could be obtained higher values of efficiency for the last LC, this valoes was fond for the coil equally spaced coils . New tests according to the distance and frequency are made to a system composed three LC. In the analysis for different distances was found ideal conditions for energy transfer to each coils. Finally, it was analyzed the influence of the frequency on eficiency of the coils. The analisys show that it is possible to prioritize the transfer of power to one coil of interest. From this study it was possible to verify the feasibility of the utilization of the wireless power transmission system to supply energy to multiple devices.

Acknowledgment

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