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Wireless Supply Design and Implementation to Power Electronics Equipment

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Abstract—this paper presents a system to wirelessly transfer energy to energize in-hand electronics equipment, to a certain distance through inductive coupling. It involves the transmission of energy from a power source to an electrical load without connectors, across an air gap. Essentially consists of two coils – a transmitter coil and a receiver coil. Because there are no mechanical connections between the transmitter and receiver, power can be transferred whenever a system is within range of a transmitter. The designed WPT system delivered 23.4 Vout of 24 V at a distance as low as 0.5cm, and it took up to 80 cm for the voltage to drop to zero.

I. INTRODUCTION

Wireless Inductive Power Transfer or IPT involves the transmission of energy from a power source to an electrical load without connectors, across an air gap.
The basis of a wireless power system involves essentially two coils – a transmitter coil and a receiver coil. The transmitter coil is energized by alternating current to generate a magnetic field, which in turn induces a current in the receiver coil.

Wireless energy transfer based on magnetic resonant coupling is most widely regarded as a breakthrough technology in our time. By having magnetic resonant coils operating at the same resonant frequency, Kurs et al. demonstrated that energy could be transferred efficiently from one source coil to one receiver coil via non radiative electromagnetic field (without any physical contact, i.e., wirelessly)[1].

The goal of this work is to study and design a wireless powertransfer system that is cost effective and can be integrated easily into devices, while ultimately providing a better wireless charging experience for consumers.
Many methods can be used for transferring power, fourmain methods are discussed here.

1st method "wires transmitting power" has an excellent performance and reliable.

The 2nd method "Low frequency – short distance – magnetic Induction" which is also reliable with good efficiency. Although it transfers through high coupling coefficient, the distance is very low with respect to a power

Transmitting through Resonant coupling at high frequency. Also it is less dangerous.

The 3rd method "high frequency – moderate distance – magnetic Resonance" is dangerous to human beings; it has few advantages in accordance to disadvantages. The distance between two coils is intermediate between the distances between two coils of power transmitting at low frequency and that of high frequency.

The 4th method "microwave frequency-long distance" is very dangerous to human beings; high frequency tends to high cell killer. However, it can transmit to a long distance which is the target of scientists.

The advantage of wireless power transfer is that it can be easy to install, maintenance free and flexible.

II. SYSTEM DESIGN

A wireless power transmission system using magnetic resonance coupling was proposed and demonstrated for supplying power at high efficiency to electrical devices in a space enclosed by metal walls. Proposed magnetic resonance coupling system is driven at a resonance frequency, which is selected to avoid eddy current loss on the surrounding metals. Here's a sketch of what is designed:

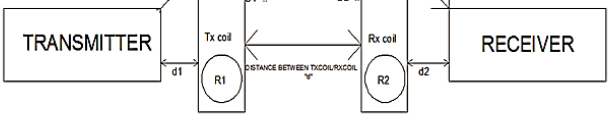

Figure 1: sketch for transmitting power wirelessly

Where:

- V_s is the voltage source.
- T_x coil: the transmitter coil with R_1 for stepping up resonant frequency.
- R_x coil: the receiver coil with R_2 for stepping down resonant frequency.
- V_r is the output voltage.
- I_r is the received current.
- "d_1" is the distance between the input loop and the T_x coil.
- "d_2" is the distance between the output loop and the R_x coil.
- "d" is the distance between T_x and R_x coil.
- "k" is the coupling coefficient.
- N_1 and N_2 represent the number of turns of T_x coil and R_x coil respectively.
- D_1 and D_2 represent the diameter of T_x coil and R_x coil respectively.

The resonant frequency and the quality factor for this resonator are

$$\omega_0 = \frac{1}{\sqrt{LC}} \tag{1}$$

And

$$Q = \sqrt{\frac{L}{C}\frac{1}{R}} = \frac{\omega_0 L}{R} \tag{2}$$

The equation for Q; describes the decreasing of losses in the circuit, through reducing R and thus increasing quality factor of the system. In highly-resonant wireless power transfer systems, Q must be high in order to transfer energy efficiently. High-Q electromagnetic resonators are typically made from conductors and components with low absorptive losses, low radiative losses and have narrow resonant frequency widths.

The efficiency of the energy exchange relies on the characteristics parameters for each resonator and the energy coupling rate between them.

One equivalent circuit for coupled resonators is the series resonant circuit is shown in Figure 2.

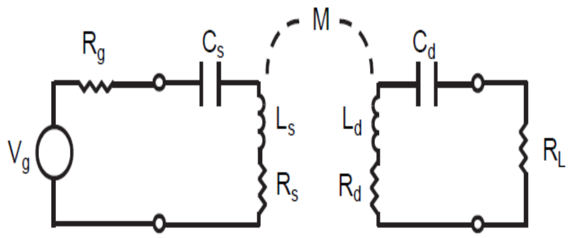

Figure 2: Equivalent circuit for the coupled resonator system.

Describing the above equivalent circuit, we have the generator a sinusoidal voltage source with amplitude Vg at frequency Wand generator resistance Rg. Also, R L C at the primary to step up the resonant frequency and to be tunneled through "M" which is the mutual inductance. Reaching the secondary side,the signal is to be stepped down through symmetrical components C_d and L_d and R_d (parasitic resistances including bothohmic and radiative losses) the coil and resonant capacitor for the respective resonators. The load is represented by an equivalent Load resistance.

The coupling coefficient can be controlled by the distance between two coils, the number of turns, and the radius of the coils.Transmit coil and receive coil is at same frequency f_0.

III. IMPLEMENTATION/SIMULATION AND TESTING

The method then discussed "Transferring Power using Resonance inductive coupling".

Magnetic Resonant coupling uses resonance to increase the range at which the energy transfer can efficiently take place.

Figure 3 shows a block diagram which the project is mainly based on.

In this part, power is going to be "received" by resonance. The two coils (TX and RX) resonate at the same frequency. Some trials are going to be implemented, discussed and analyzed starting from the input source of the transmitter. These trials tell the value of the output received voltage, and the frequency at the transmitter side in which L "Transmitter Coil" and the capacitor bank reach their resonance.Some iterations are done to achieve the resonance. The secondary side will receive the maximum power by adding a capacitor to the secondary coil.

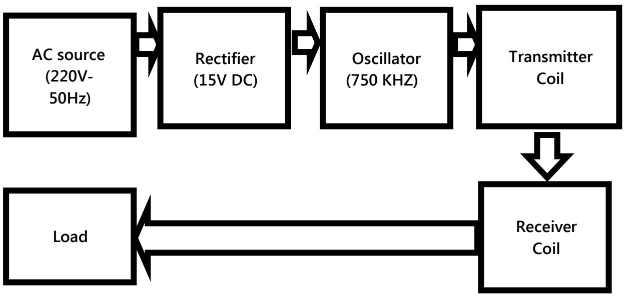

Figure 3: Block diagram of wireless power transfer system.

A. Implementation:

In this circuit, the transistor conducts and generates alternating current through the transmitter coil, which creates an electromagnetic wave.This wave captured by the receiver coil induces a current on that coil and so a voltage. The created voltage is rectified and supplied to the output,thus the LED will light up.

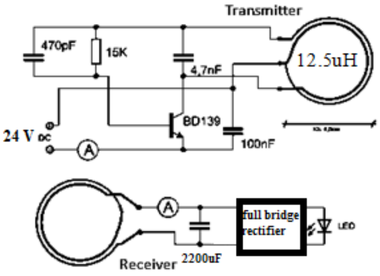

Figure 4: wireless power transmitter circuit.

The transmitter coil looks like a spiral one “3 circles. The transmitter coil used with the bank of capacitors is found to resonate at 650 KHz and the inductance of the coil L is measured ~12.5uH.A high resonance frequency leads to a higher Q, and generally improves the stability.

In the receiver side, the coil (receiver inductor) captured the signal at the resonating frequency. It was used of thickness 0.5 mm, 25 turns (circular shape). Film capacitor is used here for the resonance. Across the LC output we implemented a bridge rectifier to convert the signal to DC and an output capacitor is used to stabilize the voltage. The output load was used is a lamp of 5 Watt optimum at 0.5 cm apart.

While varying the distance between the TX and RX, the transmitted voltage and the received voltage for the circuit are measured. The following table shows thedetailed results obtained at different distance:

Table 1: Output dc voltage w.r.t distance (cm)

Dc output voltage (Vdc)	Distance (cm)
0.5	80
1.5	70
3.5	60
7	50
11	40
17	30
20	20
22.3	10
23.4	0.5

As observed, as the distance increases the output voltage will decrease instantaneously. Thus the efficiency will decrease.

The optimum voltage efficiency is observed at the smallest distance (0.5cm) =>

$$\eta = \frac{23.4}{24} = 97.5\ \%$$

A more detailed and clear look on the efficiency and the output voltage versus distance is illustrated in 2 plots below:

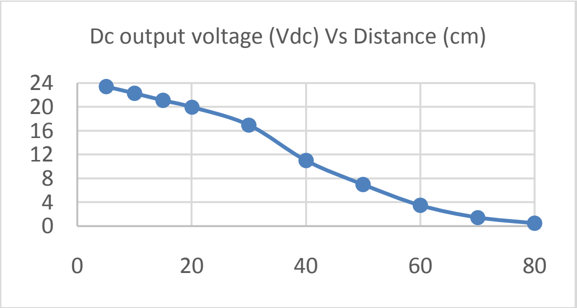

Figure 5: plot of the DC output voltage versus distance

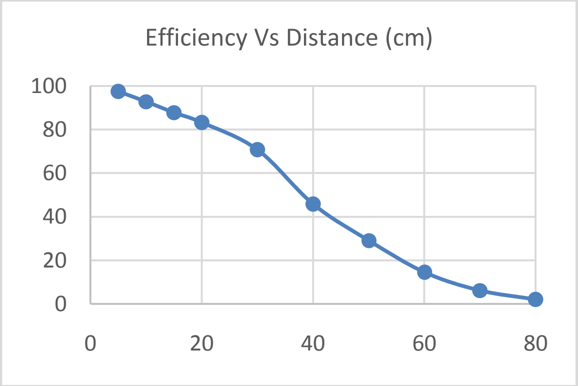

Figure 6: plot of the Efficiency versus distance

The drawback of the above system, is the lack of isolation between the load and coil 2, that is, if the load is not purely resistive, it will majorly affect the resonant frequency and so the performance of the system as a whole. So a more complex design is proposed in the next sections that reply to these constraints.

IV. A MULTIPLE COILS WPT LINK: SIMULATION ANALYSIS

The Multi-coil system is studied in the literature, and it’s one of the propositions available to increase the efficiency of the system and the distance between coils.Study and simulations are done to understand the behavior of such system. The 4 coils system is presented in the figure below. It consists of 4 coils where each 2 adjacent coils are coupled together.

The importance of the 4 coils system is to obtain isolation between the receiver coil and the load, thus no matter what is the type of the load, the frequency of resonance at the receiver side will not be affected.

The software used for the simulation was ADS “Advanced Design System” by Agilent. The simulation done took the circuit analysis form, where we used inductors and controlled the coupling coefficient between them. And we studied the effect of the change on the power transferred.

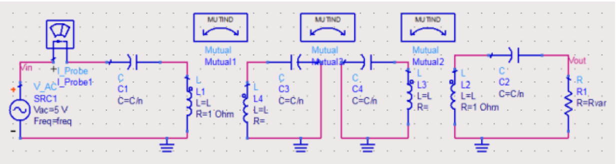

Figure 7: 4 coils resonant inductive coupling

In the circuit above we have 4 coils where each 2 adjacent coils are coupled together.

In [2], for the simplicity of the analysis, the system was assumed symmetrical, with input loop and transmit coil identical to the output loop and receive coil, respectively. As such, $L_1 = L_4$, $L_2 = L_3$, $R_1 = R_4$, $R_2 = R_3$, $C_1 = C_4$, and $C_2 = C_3$. In addition, $R_s = R_L = R_0$. The quality factor of each resonator is as follows: $Q_1 = Q_4 = \omega\ L_1 = R_0$, $Q_2 = Q_3 = \omega\ L_2 = R_2$. The coupling coefficient k_{12} is equal to k_{34}, k_{ij} where is Mij=kij /$\sqrt{LiLj}$.

The power transfer efficiency, which is defined as the power delivered to the load divided by the maximum power available, is derived as shown:

$$\eta = \frac{V_L^2/R_L}{V_s^2/4R_s} = \left[\frac{2k_{23}k_{12}^2Q_1Q_2^2}{(1+k_{12}^2Q_1Q_2)^2 + K_{23}^2Q_2^2}\right]^2 \qquad (3)$$

This efficiency can be maximized for a given k_{23} (or d_{23}) by choosing an optimum k_{12} such that:

$$\frac{\partial_{\eta}}{\partial k_{12}} = 0 \quad at \quad k_{12} = k_{12,opt} \qquad (4)$$

From this equation, $k_{12,\ opt}$ and the optimum efficiency η_{opt} are determined as:

$$k_{12,opt} = \sqrt[4]{\frac{1}{Q_1}k_{23}^2 + \frac{1}{Q_1^2Q_2^2}} \qquad (5)$$

$$\eta_{opt} = \left(\frac{2Q_2k_{23}\sqrt{Q_1^2Q_2k_{23}^2+1}}{\left(\sqrt{Q_1Q_2^2k_{23}^2+1}+1\right)^2 + Q_2^2k_{23}^2}\right)^2 \qquad (6)$$

In summary, optimum efficiency can be achieved with the distance d_{23}, if the coupling coefficient k_{12} is optimum. This theoretical analysis is proven by simulation in the next section.

A. Effect of Resonant Frequency:

Our study started to prove that to get max-power transfer, some coils should resonate at the same frequency.The simulation showed that the first 3 coils starting at source side must resonate at the same frequency while the forth coil at the load side doesn't affect the system no matter what is the frequency of its resonant circuit. This result is what we searched for in the first place and that to isolate the load side from the system.

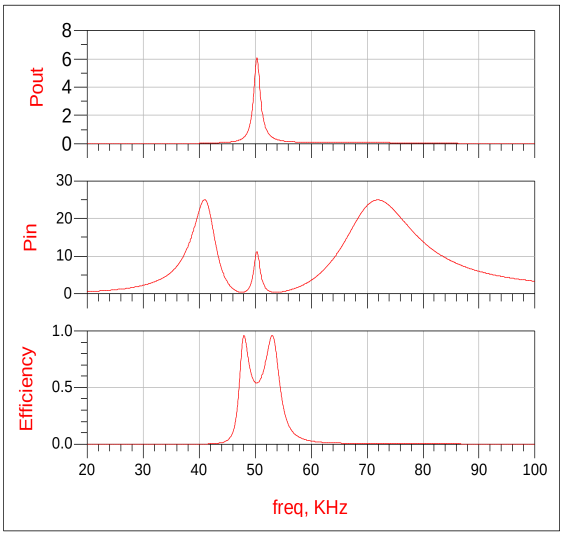

Figure 8: Power in case of same resonant for the coils

Commenting on the simulation results (Figure 8), we can note the following:

In case resonant frequency is different for all coils, not only the output received power will not be at its max value but also the efficiency will be low. High efficiency is attained when the power present at the input is low and so a low-power system.

In the 2nd case where only the middle coils resonate at the same frequency, the same results as before are obtained. The more important is that the optimum frequency (max-power transfer) at which the system should operate cannot be controlled and known in advance. It will be different from 1/2π√LC.

While, in the last case where the coils resonate at the same frequency, taken here 50 KHz, we can see that: the output power is at the highest possible value, and the efficiency at that frequency is around 60% at the resonant frequency chosen, with notably higher input power than before.

The other interesting fact, is that in all cases, the frequency at which the maximum input power is sent is different from the resonant frequency. In addition, whatever value for the resonant frequency is chosen the max-input power will exist at 2 frequencies surrounding the resonant one

B. Effect of Coupling Coefficient:

We continued our study to test the effect of the coupling coefficient at each stage on the behavior of the circuit. Remember, we have 3 coupling coefficient: Kl between coil 1 and 2 (left), Km between coil 2 and 3 (the middle ones) and Kr between coils 3 and 4 (to the right).

The following results are obtained:

- The coupling coefficients Kl and Kr must be the same at of high coupling values in order to get max-power transfer.
- The coupling between 2nd and 3rd coils (Km) need not to be obligatory max (i.e. Km=1). But it depends:

1. On the Coupling on the other Coils

Suppose that Kl and Kr are 0.9 to 1 then to get max-power we should have Km=0.4 (figure 9).And if we take Kl = Kr = 0.5, then at Km=0.1 we will have max-power.

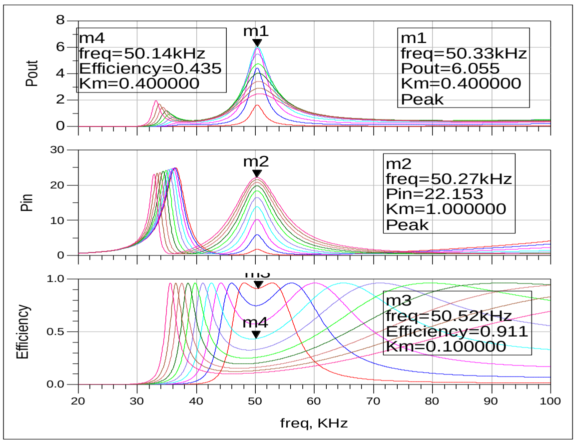

Figure 9: Power in case of same resonant for the coils

while varying the coupling coefficient between the middle coils for Kl = Kr = 0.9.

Note from the above graph, the Pout is max ≈ 6 W when Km = 0.4.

The max-input power exists at Km = 1.

The efficiency of the system at Km = 0.4 is about 44% while the max-efficiency is attained at Km = 0.1 but at lower transferred power.

Similarly, for this 2nd case, the Pout is max ≈ 6 W when Km = 0.1.

The max-input power always exists at Km = 1.

The efficiency of the system at Km = 0.1 is about 55% which is itself the max-efficiency and at Pin ≈ 10 W.

2. On the Frequency of the System

Suppose that Kl = Kr = 0.5 then at Km=0.1 we will have max-power at 50 KHz.

But to get max-power at 100 KHz resonant frequency, we should either vary Km to 0.2 to keep max-power, or we can leave Km=0.1 and vary Kl=Kr=0.3 (figure 10).

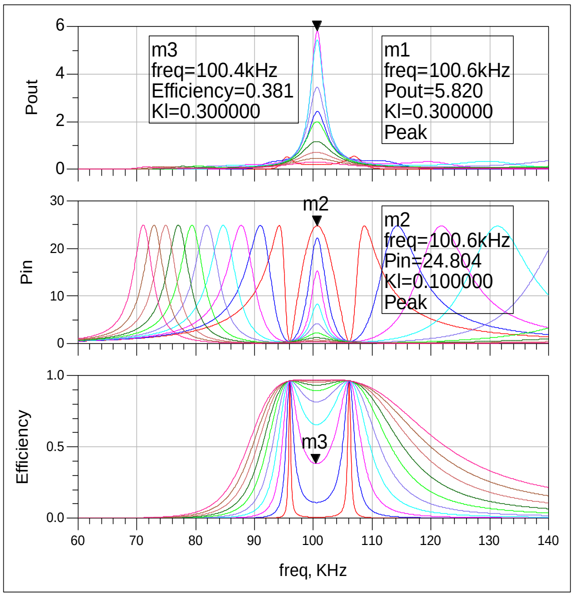

Figure 10: Power in case of same resonant for the coils while varying the coupling coefficient between the middle coils for Kl = Kr = 0.5 (third peek).

As a result, and it is an important point to get, is that, no matter what was the coupling between 2nd-3rd coils (Km), we can always control the max-power at any frequency through controlling the coupling between 1st-2nd (Kl) and 3rd-4th (Kr) coils. This means we could control the distance of transfer from the base stations represented by the middle coils through the coupling between the coils at the base.

Another remark is that, if the coupling at the center is low, then so it should be at the station with a higher fraction and not the inverse, which is clearly promising.

V. CONCLUSION

In conclusion, Wireless Power Transmission system is still far from completely eliminating the existing high-tension power transmission line cables. Yet, the ladder hould be climbed step by step. A WPT system that could be available to energize home equipment would be a big step forward.With WPT system the power could be transmitted to the places where the wired transmission is not possible. Loss of transmission is negligible level in the Wireless Power Transmission.

It is clear that resonant inductive coupling power transmission would be extremely beneficial to society if it were implemented in homes and home electronics. From an environmental standpoint, this technology could replace disposable batteries and cords, reducing dangerous chemicals and potential for poisoning communities.

Huge benefits are offered by resonant inductive coupling: medical patients who can be helped with this technology. Another benefit is the incredible convenience posed by having all your electronics powered and charged without wires to annoy you or constrict your movement.

Other people however have their doubts. Some researchers have doubts that it is safe to have the magnetic fields used in the resonant inductive coupling flowing through our bodies.

In our opinion, disadvantages of wireless power are greatly outweighed by the benefits. We summarize here some of the advantages and limitations:

Therefore, there is a conflict between high efficiency and high transfer power. However, in high power applications both high efficiency and high transfer power are essential. As a result, a compromise between high efficiency and high transfer power is needed.

- An advantage is that we can produce electricity anywhere without wires
- The power can be delivered in any direction.
- Significant de-cluttering of office space
- Reduction of e-waste by eliminating the need for power cords
- Need more light in your office, no need for electrician? Simply place the lamp where ever you need it.

While some of the disadvantages are:

- Certain resonant conditions should be satisfied; if not, no power supply takes place.
- Retrofitting old equipment or purchasing new equipment could become a very expensive endeavor.
- Possibility of “energy theft”. Wi Fi, someone can be using your internet or your power.
- Interference at very high frequency with present communication systems.

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Dr. HUSSEIN KASSEM PhD in Electronics and Masters in Telecommunications from French Universities (Brest and Bordeaux). Worked in the research field for 4 years: Development within the team of a nouvelle characterization method for the measurement of the dielectric parameters for dielectric materials, more particularly ferroelectric materials (A dielectric with very high permittivity) and LTON fields. Measurement of the variation of this permittivity under the application of an external electric field. Integration of ferroelectric films materials into microwave devices. Design of microwave filters and phase shifters. Active research design of frequency selective service filters as integrative part for use in active Radoms. Part of the academic department at the Institut Polytechnique de Bordeaux (formerly ENSEIRB) for 1 year. Now, an assistant professor at the Lebanese international university in Beirut, Lebanon.

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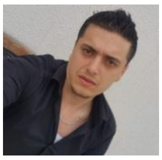

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