Electromagnetic hybrid system for levitation and wireless power transfer

Eduardo Vélez Pellicer, *Student Member IEEE* and Dr. Arturo Mediano, *Senior Member, IEEE*

***Abstract*—The goal of this research project was to investigate, design and build a system that combines levitation and wireless power transfer systems using electromagnetic fields. The system is designed for levitating a small bulb which is powered contactless by magnetic induction. This report summarizes the development of both systems: the magnetic levitator (mainly focused in the closed control loop) and the wireless power transfer link to feed the light bulb.**

***Index Terms*— closed loop systems, electromagnetic coupling, magnetic levitation, wireless power transfer.**

I. Introduction

WIRELESS power transfer is an emergent field in power electronics applications such as battery chargers for mobile devices or electric vehicles, medical implantable devices, home appliances, RFID, etc.

In this project we intended to build a demonstration prototype of a wireless power transfer link in which a given device receives energy without any physical contact.

Under the guise of creating an eye-catching system, we decided that the device was to float in the air (obviously without any wire or thread). Therefore, we decided that the device would employ an electromagnetic levitation system.

The idea is not new but the exercise is excellent to introduce students in a very interesting and fun system based in many areas of electronics and wireless systems.

II. Technology overview and design

The project has been divided into two main parts, the wireless power transfer system and the magnetic levitation system. The combination of both systems is the final goal of the project.

A. Wireless power transfer system

This technology is based in the usage of alternative flux magnetic fields to transmit energy between two inductors (air-cored coils) without physical contact.

The physical principle is the same as an electrical transformer, but removing its iron core. Since we have removed the core, the coupling coefficient (usually called *k*) between the inductors has drastically decreased and is highly dependent of the distance and orientation of the coils.

In order to improve the efficiency of the energy transfer we used the coupled resonators technique. It consists in the use of LC resonant circuits as energy emitters and receivers instead of a single coil (Fig. 1).

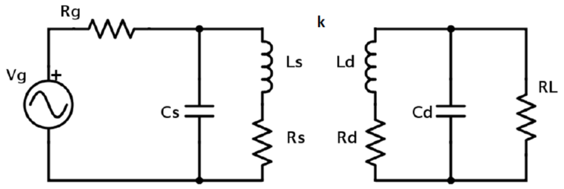

Fig. 1. Equivalent circuit of a coupled pair of resonators with source (left side of the circuit) and load (right side) connected.

In Fig. 1 the inductors Ls and Ld are the air cored coils used as energy emitter and receiver respectively, and Rs and Rd their parasitic resistances. Cs and Cd are capacitors placed in parallel to the inductors to form a resonant circuit. RL is the load (output) of the system and Vg is a frequency generator (input) with a given output impedance Rg. For proper working of the inductive coupling both circuits must be tuned at the same resonant frequency (ω_0) given by (1).

$$\omega_0 = \frac{1}{\sqrt{Ls \cdot Cs}} = \frac{1}{\sqrt{Ld \cdot Cd}} \ rad/s \tag{1}$$

Other important point in the design of the system is the quality factor, called Q, of the resonant circuits obtained by (2).

$$Q = \frac{\omega_0 \cdot L}{R} = \frac{f_0}{BW} \ rad/s \tag{2}$$

Where f_0 is the resonant frequency in Hz and BW the bandwidth at -3dB in Hz.

Q could be interpreted as the ratio between the energy that an oscillator is able to store and the dissipated energy (due to parasitic resistances) in each oscillation cycle. The higher the Q, the higher the efficiency of the link, but high Q means that the system will be more sensitive to component tolerance due small detuning implies a dramatically lack of efficiency.

B. Magnetic levitator system

A magnetic levitator consists in a system capable to float a metallic or magnetic body by the cancellation of gravitational attraction by magnetic force. Those kind of systems are inherently unstable, this is, the levitated object falls down or it gets stuck to the electromagnet.

Manuscript received January 15, 2015. Eduardo Vélez Pellicer received his BS in Telecommunications Engineering from the University of Zaragoza, Aragón, Spain (e-mail: evelez@electronicacerler.com).

Arturo Mediano and Luis Ángel Barragán are professors and members of the Group of Power Electronics (GEPM) of the Aragón Institute of Engineering Research (I3A) of the University of Zaragoza (amediano@unizar.es and barragan@unizar.es).

A picture of the system is shown in Fig. 2.

To achieve a stable levitation a closed control loop is need. The control loop needs a feedback of the object position to control de magnetic force exerted on the objet (increasing or decreasing the current by the electromagnet).

In this project, since the levitated objet contains a small magnet, a Hall Effect sensor has been used. This sensor provides a voltage at its output proportional to the magnetic field measured. The sensor is placed under the electromagnet and its output is proportional to the levitated object position.

For very small levitators this method works properly, but for larger electromagnets the magnetic field generated by the electromagnet is similar or stronger than the generated by the magnet in the levitated object, causing an undesirable feedback and instability.

To solve this problem a second Hall Effect sensor has been used, placing it at the top of the electromagnet and using both sensors to obtain a differential measure.

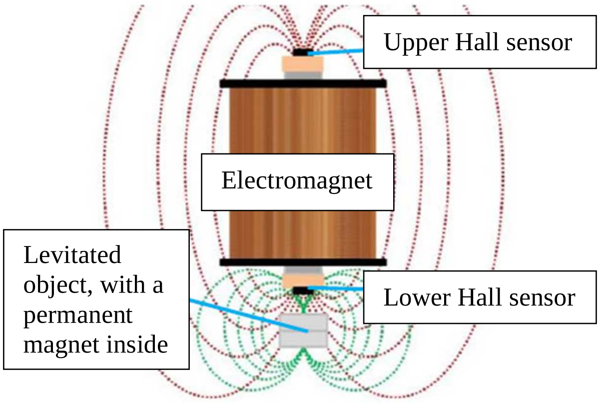

Fig. 2. Differential measure of the magnetic field. Both sensors measure the same magnitude of the electromagnet's magnetic field, but only the lower Hall sensor is sensitive to the magnetic field generated by the permanent magnet. With differential measurement the undesirable feedback could be cancelled.

In order to ensure the compatibility between both systems, the resonant frequency of the resonator circuits obtained in (1) should be higher than the bandwidth of the Hall Effect sensors to avoid interferences.

The selected sensor was the Honeywell ss495, thus, the resonant frequency will be 60 kHz, which is above the cut-off frequency of the sensors. A prototype was built (Fig. 3 and Fig.4) using a LED as system load with a consumption of 180 mW.

For the wireless power transfer system a planar *litz* wire coil of 38 µH and 0.05 Ω was used as emitter and an air cored coil of 10 µH and 0.1 Ω as receiver.

Fig. 3. Levitated object. It contains the receiver coil (covered with black tape), the resonant circuit, the permanent magnet (three neodymium disks), a LED with a silicon diffusor and a rectifier circuit to power the led. Total weight is 80 gr.

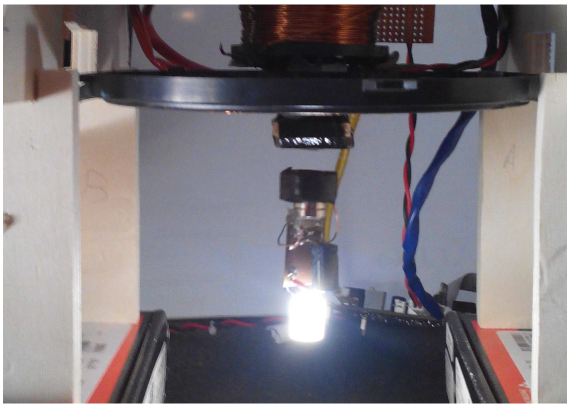

Fig.4. Prototype of the proposed system.

The prototype results in a stable levitation and working wireless power transfer link. The efficiency of the link was only 12% (theoretical calculations gave a maximum of 60% for this scenario) due not considered parasitic effects and impedance mismatching. Therefore, is ten times greater than the efficiency of the non-resonant circuit link.

IV. CONCLUSIONS

It is possible to transfer energy through the air using low frequency non-radiative magnetic fields and is compatible with other electromagnetic sensitive systems and circuits, but is necessary to improve the efficiency of the link.

In this work, the student combined many disciplines considered "hot" topics for the industry today: analog and digital electronics, control theory, wireless technology, electromagnetism, resonant systems, etc. Different software and measurement tools and instruments were needed to develop the work.

V. MTT-S SCHOLASHIP EXPERIENCE AND FUTURE PLANS

The MTT-S Scholarship gave me the opportunity to improve my end-of-degree project to finish my BS in Telecommunications Engineering and reinforced my in interest in RF electronics engineering. As for my future career plans, I am pleased to say that I have found a career in the RF and Power Electronics at Cerler Global Electronics as R&D Engineer.

VI. ACKNOWLEDGEMENT

The author would like to thank the Group of Power Electronics (GEPM) of the Aragón Institute of Engineering Research (I3A) for the support in the project development, Texas Instruments for donation of the development boards. He and the MTT-S from IEEE for the Undergraduate Scholarship.

REFERENCES

[1] T. H. Wong, "Design of a Magnetic Levitation Control System - AnUndergraduate Project". IEEE.

[2] Morris Kesler. "Highly Resonant Wireless Power Transfer: Safe, Efficient, and over distance". WiTricity Corporation, 2013.

[3] José I. Artigas, Luís A. Barragán, Sergio Llorente, Álvaro Marco. Levitador magnético de muy bajo coste con fines didácticos". SAAEI 2010.